A New General Transparency Model for Block-Based Watermarking Method

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Abstract

Blocking artifact is one of the main drawbacks of the block-based watermarking method. Though a number of researches on “transparent” digital watermarking system have been presented, all of them use their own criteria in specific domain such as the discrete cosine transform (DCT), discrete wavelet transform (DWT), etc. In this paper, a generic criterion, the local peak signal-to-noise ratio (LPSNR) is presented to ensure the transparency of block-based watermarking method. The central contribution of this paper is the proposal of an approach which takes into account the transparency in spatial domain. However, the watermark can be embedded in either spatial domain or any transform domain.

Keywords: Chaotic, LPSNR, watermark

1 Introduction

Digital watermark as a tool for copyright protection has attracted a lot of attention in the last few years. The main trend is to superimpose the watermark on the image in either an addition or a multiplicative way either in the spatial or in the transform domains. Initially, many spatial-domain techniques have been presented [4, 10], which is easy to achieve high perceptual transparency but fragile to image processing and geometric translations. Recently, most of the researchers prefer to embedding watermark in the transform domain [8, 13] for much more robustness. Many human visual system (HVS) models have also been adopted in these methods to guarantee the perceptual equivalent between the original and watermarked image [5, 12].

However, most of the HVS models are presented in specific transform domain such as the DCT, DWT domain for image compression [1, 3, 14]. As we know, watermark embedding is different from image compression in that the watermark can be embedded in not only the DCT, DWT domain, but also the discrete Fourier transform (DFT), singular value decomposition (SVD) transform domain and so on for special purposes. Many methods have been presented based on the DFT, SVD transform in the last few years [2, 9, 11]. To our knowledge, there is no HVS model has been presented based on DFT and SVD transform.

In our previous work [6], the LPSNR is adopted in a specific SVD-DCT based scheme to ensure the transparency. In this paper, the LPSNR is presented as a generic criterion to guarantee the transparency of block-based watermarking method. Whether the watermark is embedded into the spatial domain or transform domain such as the DCT, DWT, DFT, etc, the transparency of the watermarked image is determined ultimately in the spatial domain. Through using our new generic criterion LPSNR, the transparency of the watermarked image is easy to achieve. Moreover, the LPSNR can be regulated according to the watermark strength to obtain the highest possible robustness.

This paper is organized as follows. In Section 2, the definition of LPSNR is given. In Section 3, we propose a method to describe the application of LPSNR. Experimental results and conclusions are included in Section 4 and 5, respectively.

2 The Definition of LPSNR

Without loss of generality, we assume the dimension of the original image A is $M \times M$ which is split into non-overlapping $m \times m$ sub-blocks $A_k (1 \leq k \leq \frac{M}{m} \times \frac{M}{m})$ by order from left to right and then top to bottom. The LPSNR is defined as

$$LPSNR = 10 \log_{10} \frac{(L-1)^2}{\frac{1}{m^2} \sum_{u=1}^{m} \sum_{v=1}^{m} [A_k^*(u,v) - A_k(u,v)]^2},$$

where L is the number of gray levels. A_k^* is the watermarked sub-block and A_k is the corresponding un-watermarked sub-block. The subscript k denotes the index of blocks. The u and v are coordinates in the sub-blocks.

3 Application of LPSNR in Block-Based Watermarking Method

In this section, we propose a method to describe the application of LPSNR in watermark embedding. For easy of exposition, we describe a non-blind watermarking method based on DCT, although our method, in principle, is equally applicable to DFT, DWT and SVD transform etc. Moreover, the LPSNR is suitable for both blind and non-blind watermarking method. A chaotic encryption algorithm is adopted to promote the security of our method [7].

3.1 Chaotic Encryption

Consider the well-known Logistic equation

$$X_{n+1} = \mu X_n(1 - X_n), \tag{1}$$

which maps the unit interval into itself for $\mu \in [0, 4]$. We know that when $\mu > 3.57$, chaos sets in. Therefore, we should choose $\mu > 3.57$ in our encryption algorithm. Any $X_0 \in (0, 1)$ can be selected as a key. Drop the first 100 iterations and get a chaotic sequence

$$X_{101}, X_{102}, \cdots, X_{100+\frac{M}{m}\times\frac{M}{m}}, \tag{2}$$

where the length of the chaotic sequence is $\frac{M}{m} \times \frac{M}{m}$, which equals the number of the $m \times m$ sub-blocks of the original image. According to Sequence (2) we construct another sequence

$$b_1, b_2, \cdots, b_{\frac{M}{m}\times\frac{M}{m}}, \tag{3}$$

to index the sub-blocks in which we should embed the watermarking sequence. Sequence (3) is constructed as if X_{100+i} is the nth biggest number in Sequence (2), $b_i = n(1 \le i \le \frac{M}{m} \times \frac{M}{m})$. As we know (3) is a sequence without repeated items, then if $i \ne j$, $b_i \ne b_j$. For example, if the Sequence (2) is

$$0.5, 0.8, 0.7, 0.6.$$

Sequence (3) can be constructed as follows. Since the first element 0.5 is the fourth biggest number in the above sequence, the first element in the constructed sequence is 4. The second element 0.8 is the biggest number in the above sequence, so the second element in the constructed sequence is 1. In the same way, we can get a sequence

$$4, 1, 2, 3.$$

3.2 Generating the Watermarking Sequence

Selecting another initial value in Equation (1) and dropping the first 100 iterations, we get another chaotic sequence

$$X'_{101}, X'_{102}, \cdots, X'_{100+N}(1 \le N \le \frac{M}{m} \times \frac{M}{m}). \tag{4}$$

According to Sequence (5) we construct the watermarking sequence

$$w_1, w_2, \cdots, w_N. \tag{5}$$

Sequence (5) is constructed as follows. If $X'_{100+i} > 0.5$, $w_i = 1$, else $w_i = -1$.

3.3 Watermark Embedding

In this step, it is not necessary to perform DCT on all of the sub-blocks of the original image. We only perform DCT on these selected sub-blocks with indices $b_i(1 \le i \le N)$. For simplicity, in every sub-block only one element of the watermarking sequence is embedded into the selected DCT components. The DCT on these selected sub-blocks is described as

$$F_{b_i}(u, v) = DCT(A_{b_i}(u, v))(1 \le i \le N, 1 \le u, v \le m),$$

where $F_{b_i}(u, v)$ denote the DCT coefficients of the sub-blocks. The embedding algorithm is described as

$$F^*_{b_i}(u, v) = F_{b_i}(u, v) + \alpha_{b_i} w_i (1 \le i \le N, 1 \le u, v \le m), \tag{6}$$

where the $\alpha_{b_i}(1 \le i \le N)$ are adaptive scaling factors which determine the watermark strength. The LPSNR is employed in our method to determine the value of scaling factor α_{b_i}. On one hand, a lower bound L_{min} of LPSNR is chosen to ensure the transparency; On the other hand, the upper bound L_{max} of LPSNR is used to achieve the highest possible robustness. For any given sub-block, if the LPSNR value does not belong to a predefined $[L_{min}, L_{max}]$ in the spatial domain after watermark embedding, the α_{b_i} need be altered consequently in the transform domain. As we can see, the scaling factors α_{b_i} are regulated in the transform domain but determined ultimately in the spatial domain. That is to say, any transform can be adopted in our method.

After embedding, the watermarked image A^* is obtained by assembling the inverse DCT's of all the watermarked sub-blocks $F^*_{b_i}(u, v)$ and substituting them for the corresponding sub-blocks of the original image.

3.4 Watermark Extraction

The extraction is the inverse of the embedding procedure. As in the embedding step, we extract every element of the watermarking sequence from the watermarked image A^* by using

$$w_i = \begin{cases} 0, & (F^*_{b_i}(u, v) - F_{b_i}(u, v))/\alpha_{b_i} \le 0 \\ 1, & (F^*_{b_i}(u, v) - F_{b_i}(u, v))/\alpha_{b_i} > 0. \end{cases}$$

4 Experimental Results

We compare the robustness of our method with the widely used adaptive way [3]. The adaptive way is described as

$$F^*_{b_i}(u, v) = F_{b_i}(u, v)(1 + \alpha w_i)(1 \le i \le N, 1 \le u, v \le m), \tag{7}$$

where the α is the scaling factor. In these two methods, the watermarking Sequence (5) is embedded into the same components of the original image. In every sub-block only one element of the watermarking sequence is embedded into a randomly selected DCT component (in Equations (6) and (7), $1 \le u, v \le 3, u + v \ge 2$). In our presented method, we choose all our scaling factors $\alpha_{b_i}(1 \le i \le N)$ under the constraint $41 \le \text{LPSNR} \le 43$. The initial values in Equation (1) for generating the encryption sequence and the watermarking sequence are 0.8 and 0.88, respectively. The control parameter μ equals 4. The length of the watermarking sequence is 1000. For achieving the similar peak signal-to-noise ratio (PSNR) in these two methods, we select $\alpha = 0.35$ in the adaptive way. Figure 1(a) shows the original 512×512 image "Lena" which is divided into non-overlapping 8×8 sub-blocks. The PSNR value and the watermarked image "Lena" in our method is shown in Figure 1(b). We can see the difference between Figure 1(a) and 1(b) is unperceivable. Figure 1(c) is the watermarked image in the adaptive way. Though the PSNR value is much higher than 38db, the blocking artifacts are still perceptible. It is because the LPSNR values of some sub-blocks are much less than 38db. In our experiment, there are 83 LPSNR values which are less than 38db and the smallest LPSNR value is 22.5377 in the adaptive way when we choose $\alpha = 0.35$. From our various experimental results, the use of LPSNR can not only ensure the transparency, but also improve the robustness of the adopted watermarking method. To examine the robustness of the techniques, we use the latest StirMark4.0 benchmark tests [9, 10] and measure the bit error ratio (BER) that results after applying a specific attack. Simulation results are shown in Table 1.

From Table 1, we can see our algorithm performs much better than the adaptive way under the common image processing attacks such as the JPEG compression, median filtering, and adding noise. It also shown in Table 1 that our method is more efficient under the aspect ratio variation, scaling, random removal of some rows and columns (jitter attack), etc. However, Table 1 also indicates the shortcoming of our presented experimental algorithm. The algorithm failed in passing some geometry distortions such as the affine transform, rotation, latest small random distortions, small random distortions, etc. A resynchronization module should be adopted to improve the robustness of our algorithm. While we do appreciate it, in this paper, we only want to demonstrate the efficiency of the application of LPSNR in block-based watermarking method.

5 Conclusions

In this paper, a generic criterion, the LPSNR, is presented to ensure the transparency of block-based watermarking method. On the other hand, the LPSNR can also be used to achieve the highest possible robustness in some watermarking methods. It is a generic criterion and can

(a) Original image "Lena"

(b) Watermarked image in our method (PSNR=48.6224)

(c) Watermarked image in an adaptive way (PSNR=48.1892)

Figure 1: Original image and watermarked images

Table 1: Test results under StirMark 4.0

StriMark Functions	BER(%)		StriMark Functions	BER(%)	
	(LPSNR)	Adaptive)		(LPSNR)	(Adaptive)
1_row_1_col_removed	0	1.3	Noise_1	0.30	20.90
1_row_5_col_removed	2.30	5.60	Affine_1_0.01 _0_0.01_1_0	35.20	36.70
5_row_1_col_removed	2.80	6.80	Affine_1.010_0.013 _0_ 0.009_1.011_0	51.30	47.40
1_row_17_col_removed	3.20	11.50	Ratio_x_0.80_y_1.00	0.80	3.30
17_row_1_col_removed	3.40	16.10	Ratio_x_1.00_y_0.80	0.30	5.40
3×3_median_filter	4.40	14.50	Ratio_x_1.00_y_1.20	0.30	5.20
3×5_median_filter	15.30	31.70	Ratio_x_1.20_y_1.00	0.60	4.60
Cropping_5	8.60	23.60	Rotation_0.25	13.20	26.30
Cropping_10	21.70	48.70	Rotation_-0.25	15.30	21.80
JPEG_30	0	29.40	Rotation_scale_0.25	25.30	28.70
JPEG_25	3.50	33.10	Rotation_scale_-0.25	28.60	12.50
JPEG_20	9.20	34.80	Scale_50	1.90	2.60
JPEG_15	23.70	37.90	Scale_200	3.10	4.60
LatestSmallRandom Distortions_0.95	46.10	49.00	SmallRandom Distortions_0.95	45.10	48.10
LatestSmallRandom Distortions_1	45.60	49.60	SmallRandom Distortions_1	45.90	48.50
LatestSmallRandom Distortions_1.05	45.30	48.60	SmallRandom Distortions_1.05	47.10	49.80
LatestSmallRandom Distortions_1.1	45.60	48.90	SmallRandom Distortions_1.1	47.20	47.80

be used in any of the block-based transform domain, such as the DFT, DWT, SVD, etc. Moreover, it can be used to modulate a carrier signal in any of a variety of ways, e.g., amplitude, frequency, phase, etc.

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References

[1] M. G. Albanesi, and F. Guerrini, "An HVS-based adaptive coder for perceptually lossy image compression," *Pattern Recognition Letters* vol. 36, pp. 997-1007, 2003.

[2] D. V. S. Chandra, "Digital image watermarking using singular value decomposition," *Proceedings of 45th IEEE Midwest Symposium on Circuits and Systems*, pp. 264-267, Tulsa, OK, Aug. 2002.

[3] F. X. Coudoux, M. Gazalet, and P. Corlay, "Reduction of blocking effect in DCT-coded images based on a visual perception criterion," *Signal Processing: Image Communication*, vol. 11, pp. 179-186, 1998.

[4] V. Darmstaedter, J. F. Delaigle, J. J. Quisquater, and B. Macq, "Low cost spatial watermarking," *Computer and Graphics*, vol. 22, no. 4, pp. 417-424, 1998.

[5] J. F. Delaigle, C. D. Vleeschouwer, and B. Macq, "Watermarking algorithm based on a human visual model," *Signal Processing*, vol. 66, pp. 319-335, 1998.

[6] F. Huang, and Z. H. Guan, "A hybrid SVD-DCT watermarking method based on LPSNR," *Pattern Recognition Letters*, vol, 25, no. 15, pp. 1769-1775, 2004.

[7] F. Huang, and Z. H. Guan, "Cryptosystem using chaotic keys," *Chaos, Solitons and Fractals*, vol. 23, pp. 851-855, 2005.

[8] J. Huang, and Y. Q. Shi, "Reliable information bit hiding," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 12, no.10, pp. 916-920, 2002.

[9] X. Kang, J. Huang, Y. Q. Shi, and Y. Lin, "A DWT-DFT composite watermarking scheme robust to both affine transform and JPEG compression," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 13, no. 8, pp. 776-786, 2003.

[10] N. Nikolaidis, and I. Pitas, "Robust image watermarking in the spatial domain," *Signal Processing*, vol. 66, pp. 385-403, 1998.

[11] S. Pereira, and T. Pun, "Robust template matching for affine resistant image watermarks," *IEEE Trans-*

actions on Image Processing, vol. 9, no. 6, pp. 1123-1129, 2000.

[12] S. Suthaharan, S. W. Kim, H. K. Lee, and S. Sathananthan, "Perceptually tuned robust watermarking scheme for digital images," *Pattern Recognition Letters*, vol. 21, pp. 145-149, 2000.

[13] Y. Wang, J. F. Doherty, and R. E. Van Dyck, "A wavelet-based watermarking algorithm for ownership verification of digital images," *IEEE Transactions on Image Processing*, vol. 11, no. 2, pp. 77-88, 2002.

[14] A. B. Watson, R. Borthwick, and M. Taylor, "Image quality and entropy masking," *Proceedings SPIE Conference Human Vision, Visual Processing, and Digital display VI*, vol. 3016, pp. 2-12, Jul. 1997.

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