An Improved Blind Watermarking Scheme in Wavelet Domain

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ABSTRACT: *The trade-off between the imperceptibility and robustness is one of the most challenges in digital watermarking system. To solve the problem, this paper proposes an improved blind digital watermarking algorithm for images based on the combination of Discrete Wavelet Transform (DWT) decomposition and Particle Swarm Optimization (PSO). For protecting the copyright information of a digital image, the watermark preprocessed with an affine scrambling is embedded in the vertical subband (HL_m) coefficients in wavelet domain. Furthermore, the proposed algorithm based on PSO is performed to train scaling factors to accomplish maximum the watermark strength while decrease the visual distortion. Simulation results demonstrate the proposed watermarking procedure has the remarkable performance in robustness to various attacks and the superiority of the proposed scheme.*

Keywords: watermarking, Blind, Discrete Wavelet Transform, Particle Swarm Optimization

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1. Introduction

With the popularization and development of multimedia technologies and the spread of high-speed communication networks, it is proliferated that various digital multimedia products such as image, audio, video and three-dimensional model are more vulnerable to illegal possession, duplication and dissemination than analog data. Consequently, multimedia digital content owners are skeptical of putting their content on the Internet due to lack of intellectual property protection available to them. Digital watermarking is the process of embedding or hiding digital information called watermark into a multimedia product, and then the embedded data can later be extracted or detected from the watermarked product, for protecting digital content copyright and ensuring tamper-resistance, which is indiscernible and hard to remove by unauthorized persons [1].

These years, the discrete wavelet transform (DWT) approach remains one of the most effective techniques that is easy to implement for image watermarking [2-4]. In [3], a distance measure between the distorted and undistorted images/video in order to determine the distortion is introduced, but the algorithm is non-blind. Lee et al [4] presents a Genetic Algorithm-Based watermarking algorithm in the discrete wavelet transform domain. The algorithm consists of wavelet-domain low-frequency region watermark insertion and genetic algorithm-based watermark extraction. However, because most of the energy is concentrated in the lowest frequency component in DWT domain, the coefficients modification of approximation subband cause serious visual distortion and in the GA, there exist drawbacks which are its expensive computational cost and the low convergence speed.

In this paper, a novel robust blind watermark extraction scheme using PSO in DWT domain is proposed. The watermark insertion is implemented in the vertical subband (HL_m) component of DWT domain, and particle swarm optimization (PSO) searches and extracts watermark automatically. This scheme can also simultaneously optimize multiple scaling factors to obtain the highest possible robustness without losing the transparency, in embedding the watermark image.

2. Preliminaries

2.1 Discrete wavelet transform (DWT)

The DWT separates an image into a lower resolution, label the resulting sub-images from an octave of it as LL (the approximation) which is the coarse overall shape, covers the low-frequency component that contain most of the energy in the image and LH (horizontal details), HL (vertical details) and HH (diagonal details) which represent higher-frequency detailed information have the finer scale wavelet coefficients, according to the filters used to generate the sub-image. The wavelet components are then used to obtain the next coarse overall shape by further iterating LL_1 in this process and we get the details (LL_1, LH_1, HL_1, and HH_1) at each succeeding octave are one-fourth the size of the previous one. This process is repeated several times until the desired final scale is reached. In DWT, most of the energy is concentrated in the lowest frequency component, in which embedding watermark is robust against various attacks but the fidelity of host image is degraded.

2.2 Particle swarm optimization (PSO)

The basic idea of the classical particle swarm optimization (PSO) algorithm is the clever exchange of information about the global and local best values mentioned above. Let us assume that the optimization goal is to maximize an objective function f(r). Each particle will examine its performance through the following two views. Each potential solution is also assigned a randomized velocity, and the potential solutions, called particles, correspond to individuals. Each particle in PSO flies in the *D*-dimensional problem space with a velocity dynamically adjusted according to the flying experiences of its individuals and their colleagues. The location of the i^{th} particle isrepresentedas , where $x_{id} \in [l_d, u_d]$, $d \in [1, D]$. l_d and u_d are the lower and upper bounds for the d^{th} dimension, respectively. The best previous position (which gives the best fitness value) of the particle is recorded and represented as $P_i = [p_{i1}, p_{i2}, \ldots, p_{iD}]$, which is also called pbest. The index of the best particle among all the particles in the population is represented by the symbol. The location p_g is also denoted by gbest. The velocity of the i_{th} particle is represented by and is clamped to a maximum $V_{max} = [v_{max1}, v_{max2}, \ldots, v_{maxD}]$ velocity which is specified by the user. The particle swarm optimization concept consists of, at each time step, regulating the velocity and location of each particle toward its and locations according to (1) and (2), respectively.

$$v_{id}^{n+1} = wv_{id}^{n} + c_1 r_1^{n}(p_{id}^{n} - x_{id}^{n}) + c_2 r_2^{n}(p_{gd}^{n} - x_{id}^{n}) \qquad (1)$$

$$x_{id}^{n+1} = x_{id}^{n} + v_{id}^{n+1} \qquad (2)$$

Where *w* is the *inertia weigh*; c_1, c_2 are two positive constants, called *cognitive* and *social* parameter respectively; $d = 1,3,\ldots,D;\ i = 1,3,\ldots,m$ and *m* is the size of the swarm; r_1^n, r_2^n are two random sequences, uniformly distributed in [0,1]; and $n = 1,3,\ldots,N$ denotes the iteration number, N is the maximum allowable iteration number.

3. The proposed Scheme

It is well known that embedding watermark information into the lowest frequency sub-band in DWT domain would cause serious effects the transparency of watermarked image, in spite of robustness against various signal processing. In this section, a brief overview of the proposed watermark embedding and watermark extracting processes is presented in DWT domain with good visual quality and reasonable resistance to various attacks. And the PSO optimization of the novel scheme is described.

3.1 Watermark embedding

Suppose that original image I is a gray-level image and $I_M \times I_N$ is the width by height of , respectively. The watermark is a binary image W_J X W_K and is the width by height of W , respectively. The original image is decomposed into The wavelet representation of m levels and obtain multi-resolution presentation (LH_m,HL_m,HH_m) and approximation (LH_3) as shown in Fig.1. $I_m^{\theta}(i, j)$ is a frequency coefficient in coordinate (i , j), where represents the orientation and $m\in\{1,2,3\}$. In consideration of the visual quality and the robustness, the proposed algorithm that a binary watermark is embedded into HL_3 component is formulated as follows:

1. In the embedding process, the original image is decomposed into m-level sub-bands to obtain a series of multi-resolution fine sub-shapes, HL_i , LH_i and HH_i (i=1,2,3) and the coarse overall shape LL_3. The HL_3 component is decomposed into non-overlapping blocks M_k with size 2 x 2, and $k=1, 2,\ldots,W_J \times W_K$.

2. The watermark information (W_J X W_K) need be pretreated in order to eliminate the correlation of watermark image pixels and enhance system robustness and security. For the advantages of lowing computed complexity and obtaining inverse transform easily comparing with Arnold transform, the watermark image is pretreated through affine scrambling. The affine scrambling is showed as equation,

$$\begin{pmatrix} u' \\ v' \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} u \\ v \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix},\ where\left(\begin{vmatrix} a & b \\ c & d \end{vmatrix} \neq 0\right) \qquad (3)$$

For enhancing the statistical imperceptible through embedding watermark, series of {-1, 1} values substitute for {0,1} which is the value of watermark image by scrambling, respectively. The new watermark is generated $w'_i = w_i \cdot p_i$,according to a sequence of the binary pseudo-random p_i modulating the watermark, where $p_i \in \{-1,1\}$ and $0 \leq i < W_k \times W_J$

3. In HL_3 component, embedding eachbit watermark information into each M_k is motivated by experiment. In each block, $\max\{I_3^{HL}(i,j), I_3^{HL}(i+1,j), I_3^{HL}(i,j+1), I_3^{HL}(i+1,j+1)\}$ and $\min\{I_3^{HL}(i,j), I_3^{HL}(i+1,j), I_3^{HL}(i,j+1), I_3^{HL}(i+1,j+1)\}$ are calculated, and sub-bands coefficients are then modified according to the equation,

$$I_3^{'HL}(i,j) = \begin{cases} max\{I_3^{HL}(i,j), I_3^{HL}(i+1,j), I_3^{HL}(i,j+1), I_3^{HL}(i+1,j+1)\} + \alpha_i w_k, if \ \ w_k = 1 \\ min\{I_3^{HL}(i,j), I_3^{HL}(i+1,j), I_3^{HL}(i,j+1), I_3^{HL}(i+1,j+1)\} - \alpha_i w_k, if \ \ w_k = 0 \end{cases} \qquad (4)$$

Where are the scaling factors.

4. Watermark bits are embedded into the original image and level inverse wavelet transform of the sub images is performed. Then, the watermarked image can be obtained.

3.2 Watermark extraction

The watermark extraction is the reverse procedure of the watermark embedding. It can be summarized as follows:

1. In the extracting process, the watermarked image is decomposed into 3-level using DWT to obtain a series of high-frequency subbnads and a high-energy subband.

2. HL_3component is decomposed into non-overlapping blocks M_k with size 2 x 2, In each block

$$X = \max\{I_3^{HL}(i,j), I_3^{HL}(i+1,j), I_3^{HL}(i,j+1), I_3^{HL}(i+1,j+1)\} \quad \text{and}$$
$$Y = \min\{I_3^{HL}(i,j), I_3^{HL}(i+1,j), I_3^{HL}(i,j+1), I_3^{HL}(i+1,j+1)\}$$

,are calculated. Then, Average(i , j) = 0.5(x+y) is defined.

3. A complete watermark sequence is obtained and inverse affine transform perform on the sequence, then binary watermark image has been extracted.

$$W_k = \begin{cases} 1, & Average(i,j) \leq I_3^{'HL}(i,j) \\ 0, & Average(i,j) > I_3^{'HL}(i,j) \end{cases} \qquad (5)$$

4. After extracting the watermark, normalized correlation coefficients to quantify the correlation between the original watermark and the extracted one is used. A normalized correlation (NC) between w and is defined as:

$$NC = \frac{\sum_{K=1}^{W_k \times W_J} W_K W'_K}{\sqrt{\sum_{K=1}^{W_k \times W_J} W_K^2 \sum_{K=1}^{W_k \times W_J} W'^2_K}} \qquad (6)$$

Figure 1. Three-level wavelet transform

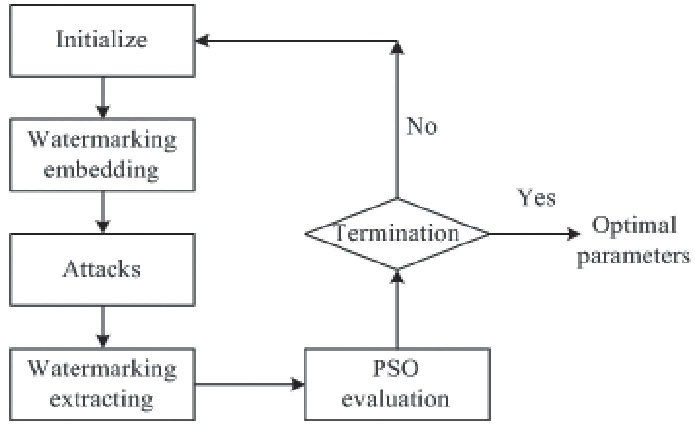

Figure 2. Diagram for proposed scheme

where W_k and W'_k denote an original watermark and extracted one, respectively.

3.3 Proposed optimization process

In order to achieve the optimal performance of a digital image watermarking algorithm, the developed technique employs PSO algorithm to search for optimal parameters. In the optimization process, the parameters are the scaling factors (a_l)which are obtained for optimal watermarking depending on both the transparency and the robustness factors. In every swarm, each member vector or particle in the particle represents a possible solution to the problem and hence is comprised of a set of scaling factors. To start the optimization, PSO use randomly produced initial solutions generated by random number generator between 0 and 1. In the proposed scheme, for solving optimization problem for multiple parameters, (a_l) in Eq.(4) is a weight of each watermarked bit and embedded each modulating watermarked bit into HL_3 sub-band component by DWT transform and therefore, all of (a_l) represent the multiple scaling factors. After modifying the HL_3 sub-band coefficients of the decomposed host image by employing the scaling factors, the watermarked images of the current generation are calculated according to the watermark embedding procedure explained in Section 3.1

In order to evaluate the feasibility of extracted watermark, both a universal quality index (UQI) [5] and NC values evaluate the objeqtive function as performance indices. Image quality is usually measured UQI values between the original image $x=\{x_i| i=1,2,...,256 \times 256\}$ and watermarked image $y=\{y_i|i=1,2,...,256 \times 256\}$

$$UQI = \frac{4\sigma_{xy}\bar{x}\,\bar{y}}{(\sigma_x^2+\sigma_y^2)[\bar{x}^2+\bar{y}^2]} \qquad (7)$$

Where

$$\bar{x}=\frac{1}{N}\sum_{i=1}^{N}x_i,\ \bar{y}=\frac{1}{N}\sum_{i=1}^{N}y_i,\ \sigma_x^2=\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})^2,\ \sigma_y^2=\frac{1}{N-1}\sum_{i=1}^{N}(y_i-\bar{y})^2 \text{ and } \sigma_{xy}\frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})$$

Due to UQI's role of imperceptibility measure, it is used as output image quality performance index. Similarly, *NC* is used as a watermark detection performance index because of its role of robustness measure. The maximum of objective value *V* can be calculated with

$$V=UQI \times NC \qquad (8)$$

The attacks that were utilized in the process of the objective function evaluation were: median filter, Gaussian noise and rotation for obtaining the optimal scaling factors with calculating the values of *UQI* and *NC*. In simulations of PSO, a set of parameter values are identified. In the proposed scheme, the size of the initial particle for PSO is 30, =1, =1. The PSO process is repeated until the scaling factors are optimally found. Optimization diagram for digital image watermarking using PSO is shown in Fig.2.

4. Experimental results

In this section to evaluate the performance of the proposed watermarking scheme had been tested on the grayscale 8-bit image of size 512×512 "Lena" and the 3-level wavelet decomposition Daubechies 9/7 filter coefficients are used. A 3232 binary image "UMP" is used as the watermark W and in order to eliminate the correlation of watermark image pixels and enhance system robustness and security through affine scrambling. As are shown in Fig .3. (a) and (b),respectively. And watermarked image is shown in Fig.3.(c).

a b c

Figure 3. (a) original image, (b) watermark and (c) watermarked image

Attacks	GF	TR	MF	RT	SP	CP
Watermark extraction						
UQI	0.9884	0.9903	0.9879	0.9872	0.9845	0.9851
NC	0.8751	0.9102	0.7858	0.7824	0.8928	0.8962

Table 1. The experimental results under different attacks

A good watermark scheme should be robust against different kind of attacks. In order to illustrate the robust nature of our watermarking scheme, robust test for various signal processing such as Gaussian filtering (0,0.003) (GF), median filtering (3 x 3) (MF), sharpening(SP), translating(30 pixel)(TR), rotating(30^o)(RT) and cropping(30%) (CP). Table 1 presents the UQI and NC value of the detailed experiment results.

JPEG Quality	[2] scheme	[6] scheme	Proposed scheme
90%	0.9624	1	1
75%	0.7953	0.8614	0.9273
60%	0. 6572	0.7925	0.8461
40%	0.5872	0.6937	0.8103

Table 2. The comparison results with existing schemes

In addition, the NC value of watermark embedding at JPEG compression is evaluated over various compression factors. By comparison with several existing schemes, it is evident that the proposed scheme has better performance than [2] and [6] as shown in Table 2.

4. Conclusions

Digital watermarking technique to obtain the highest possible robustness without losing the transparency is still one of the most challenging issues. This paper presents an optimal robust image watermarking technique based on DWT. In this scheme, firstly, the watermark is embedded into the vertical subband (HL_m) coefficients in wavelet domain, and subsequently, scaling factor a_l is trained by PSO which represents the intensity of embedding watermark instead of heuristics. The experimental results demonstrated that the proposed optimal watermarking scheme has strong robustness to a variety of signal processing and distortions. This simultaneously proves the more effective implementation of the novel scheme in comparison with existing schemes.

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