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Hybrid particle swarm optimization for robust digital image watermarking

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This paper presents an image watermarking algorithm for the optimization between robustness and transparency which is recently considered as one of the most challenging issues. The novelty is to associate the Hybrid Particle Swarm Optimization (HPSO), instead of a single optimization, as a model with singular value decomposition (SVD). To embed and extract the watermark, the singular values of the blocked host image are modified according to the watermark and scaling factors. A series of training patterns are constructed by employing between two images. Moreover, the work takes accomplishing maximum robustness and transparency into consideration. HPSO method is used to estimate the multiple parameters involved in the model. Simulation results demonstrated that the proposed scheme can effectively improve the quality of the watermarked image and resist common image manipulations such as adding noise, resizing compression, tempering, etc. and some geometric attacks.

Key words: Watermarking, singular value decomposition (SVD), hybrid particle swarm optimization (HPSO).

INTRODUCTION

Over the past several decades, digital information science has emerged to seek answers to the question: can we ensure tamper-resistance and protect the copyright of digital contents by storing, transmitting and processing information encoded in systems where digital content can easily be disseminated through communication channels? Today, it is understood that the answer is yes, and many research groups around the world are working towards the highly ambitious technological goals of protecting the ownership of digital contents, which would dramatically protect inventions represented in digital form for being vulnerable to illegal possession, duplication and dissemination. 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 in discernible and hard to remove by unauthorized persons (Cox et al., 1997).

There are several important issues for evaluating a watermarking system. First, it is significant to keep the imperceptibility of the host image after the encoding with watermark information. The embedded watermark should not distort the perceived quality of the unwatermarked image. The perceptual similarity should be maintained between the original and watermarked versions. Second, the watermark is resilient to attacks as many as reasonably possible, however, it is impossible for a watermarking system to be robust against all signal processing operations and geometric attacks whereas the requirement is a subordinate and dependent application. The embedded watermark should be robust so that it is not easily removable, and only the owner of the image ought to be able to extract the watermark. Therefore, the conditions of imperceptibility and robustness are conflicted

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and limited by each other. One may want to increase the watermarking strength in order to increase the robustness but these results in a more perceptible watermark. On the other hand, under the condition of imperceptibility, a watermark would have to be created with the maximum possible separation to avoid the situation where a small corruption of the watermarked image would lead to erroneous watermark detection. As a result, a good trade-off between two requirements has to be achieved.

The singular value decomposition (SVD) (Kenneth et al., 2010) was originally developed by geometers, who wished to determine whether a real bilinear form could be made equal to another by independent orthogonal transformations of the two spaces it acts on. SVD is one of the most useful techniques of linear algebra with several applications in image compression, watermarking, and other fields of signal processing (Andrews and Patterson, 1976; Knockaert et al., 1999). Over the last few years, watermarking schemes were explored based on singular vectors in SVD domain (Basso et al., 2009; Chang et al., 2005; Chang et al., 2007; Chung et al.,, 2007; Fan et al., 2008). Chang et al. (2005) proposed a SVD-based watermarking scheme, which explored the characteristics of the D and U components. In this scheme, if the magnitude difference matched the embedding watermark, the coefficients of the U component remained unchanged. And if the magnitude difference did not match the embedding watermark, the coefficients must be modified. Fan et al. (2008) presented two notes: only the coefficients in the first column of U component and V component were modified for robust SVD-based watermarking. U component or V component was used to embed watermark bit, and V component or U component was adopted to compensate a visible distortion when embedding watermark into component of SVD. Chung et al. (2007) gave a guideline to embed the watermark into both U and V components of the images. However, it was important to mention that the previously cited watermarking schemes based on singular vectors did not preserve the orthgonalization of the U and V matrices. To preserve the quality of watermarked image, it was necessary to present an approach to reorthgonalization. Unfortunately, it was difficult to embed the watermark into the singular vectors of the host image while reorthgonalizing.

Recently, several watermarking techniques had already proposed to embed into singular value in SVD domain (Bao and Ma, 2005; Bhatnagar et al., 2011; Chandra, 2002; Kong et al., 2006; Mohammad et al., 2008; Vivekananda et al., 2011). Following Chandra et al. (2002), an watermarking technique could be used for embedding both visual and pseudorandom number sequence watermarks. It presented techniques of embedding watermark globally by computing the SVD of the entire image as well as locally by computing SVD in small non-overlapping blocks of the image. Wu et al. (2011) focused on the small sized host image. Their proposed scheme was to scale up the size of original image equal to the size of watermark via over-sampling. A gray scale watermark was embedded in the low frequency sub-band at the finest level using singular value decomposition using stationary wavelet transform.

Mohammad et al. (2008) presented two versions of the algorithm. The first one assumed the size of the watermark W to be equal to the size of the original image A. The second version partitioned the host image into $M \times M$ blocks. This technique embedded one bit of the watermark in each block. In addition, the quantization index modulation had become one of the popular watermarking schemes, especially in the SVD domain (Bao and Ma, 2005; Vivekananda et al., 2011). It had good performances in terms of imperceptibility, data payload, and robustness for its simplicity and good rate-distortion-robustness tradeoffs.

Liu and Tan (2002) presented a novel digital image watermarking method based SVD. Because SVD was, in fact a one-way decomposition algorithm and is optimal matrix decomposition in a least square sense, the new method performs well both in resolving rightful ownership and in resisting common attacks.

Aslantas (2008, 2009) presented two optimized watermarking schemes using genetic algorithm (GA) and differential evolution algorithm to obtain multiple scaling factors for watermark embedding based on SVD-based (Liu and Tan, 2002) watermarking method. However, Zhang and Li (2005) stated that, the watermarking method was fundamentally flawed in that the extracted watermark was not the embedded watermark but determined by the reference watermark. The reference watermark generated the pair of SVD matrices employed in the watermark detector. In the watermark detection stage, the fact that the employed SVD matrices depended on the reference watermark biased the false positive detection rate such that it had a probability of one. Hence, any reference watermark that is being searched for in an arbitrary image can be found. However, less research work has been reported so far on the corrected optimal SVD-based image watermarking scheme. In this paper, a corrected SVD-based optimal watermarking techique is proposed for ownership protection based on hybrid particle swarm optimization (HPSO). The singular values of the host image are modified by embedding the watermark into the blocked host images according to employing multiple scaling factors. The HPSO, individuals and new generation are created, not only by crossover and mutation operators as in GA, but also by particle swarm optimization. In this way, a set of optimal solutions is calculated in only one run, without a priori restrictions. This scheme can optimize simultaneously multiple scaling factors to obtain the highest possible robustness without losing the transparency. Experimental results show both the significant improvement in transparency and the robustness under attacks.

SINGULAR VALUE DECOMPOSITION (SVD)-BASED WATERMARKING ALGORITHM

Singular value decomposition

The singular value decomposition (SVD) of a matrix with real or complex entries is one of the fundamental tools of mathematics. This type of algorithms has proven to be robust in watermarking systems. It was given detailed properties and other applications for SVD in (Bao et al., 2005). In this section, we summarize the definitions of SVD and the SVD-based watermarking scheme.

Although, SVD works for any $N \times M$ matrix, and without loss of the generality, our discussion will be limited in the $N \times N$ matrix with real entries. It is noted that the SVD applies more generally to complex-valued rectangular matrices, while we restrict our discussion to real-valued, square matrices. The singular value decomposition of A is represented by:

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

where U and $V \in R^{N \times N}$ are the unitary matrix, and $\Sigma \in R^{N \times N}$ is a diagonal matrix and the superscript T denotes matrix transposition. The diagonal elements of Σ, denoted by σ_i are called the singular values of A and these are assumed to be arranged in decreasing order $\sigma_i \geq \sigma_{i+1}$. The columns of U denoted by U_i's are called the left singular vectors while the columns of V denoted by V_i's are called the right singular vectors of A. It is easy to see that σ_i, V_i and U_i satisfy:

$$AV_i = \sigma_i U_i \tag{2}$$

$$U_i^T A = \sigma_i V_I^T \tag{3}$$

Watermarking scheme is fundamentally flawed algorithm, this is because one attacker can always claim that this watermark was the embedded one and he can claim ownership of the watermarked image, using the singular vectors of any fake watermark in the detection stage (Liu et al., 2005). For correcting fault scheme, a SVD-based watermarking algorithm, which explores the optimal scaling factors of watermark embedding, is presented.

Watermark preprocessing

The watermark information W_s ($w_k \times w_j$) need to 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 easily inverse transform. The binary watermark is pretreated through affine scrambling. The affine scrambling is shown as,

$$\begin{pmatrix} u^{'} \\ v^{'} \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix}, \text{ where } \left(\begin{vmatrix} a & b \\ c & d \end{vmatrix} \neq 0 \right) \tag{4}$$

For enhancing the statistical imperceptible through embedding watermark information, series of $\{-1,1\}$ values substitute for $\{0,1\}$ which is the value of watermark image by scrambling. The new watermark is generated W ($w_i^{'} = w_i \cdot p_i$), according to a sequence of the binary pseudo-random p_i modulating the watermark, where $p_i \in \{-1,1\}$ and $0 < i < k \times j$.

Watermark embedding scheme

Without loss of the generality, A and W are assumed to be $N \times N$ and $M \times M$ square matrices, respectively. Their algorithm consists of the following steps:

1. Partition the host image into $M \times M$ blocks ($A_{i,j}$) and perform SVD on the original image on each bock. As

$$A_{i,j} = U_{i,j} \Sigma_{i,j} V_{i,j}^{T} \tag{5}$$

2. Extract the largest coefficient $\sigma_{i,j}^{1}$ from each $\Sigma_{i,j}$ component and quantize it by using a factor α by W that is pretreated through affine scrambling. Let

$$\sigma_{i,j}^{1*} = \sigma_{i,j}^{1} + \alpha w_i^{'} \tag{6}$$

3. Perform the inverse of the SVD transformation to reconstruct the watermarked image and obtain each bock of the watermarked image A_w as

$$A_{i,j}^{*} = U\Sigma_{i,j}^{*} V^{T} \tag{7}$$

Here, α is a scaling factor which controls the strength of the embedded watermark and
$w_i^{'}(i=1,...,k \times j)$.

Watermarking extracting scheme

To extract the watermark from a possibly distorted water

marked image $A_w^{'}$, their algorithm proceeds as follows:

1. Partition the watermarked image into $M \times M$ blocks ($A_{i,j}^{*'}$).

2. Obtain the corrupted matrix Σ_n^{*} on each block as

$$\Sigma_{i,j}^{*'} = U_{i,j}^{T} A_{i,j}^{*'} V_{i,j} \qquad (8)$$

3. Extract the largest coefficient $\sigma_{i,j}^{1'}$ from each $\Sigma_{i,j}^{*'}$ component and get the possibly distorted watermark W^{*} as,

$$w_i^{*} = 1/\alpha(\sigma_{i,j}^{1'} - \sigma^{1}) \qquad (9)$$

A complete watermark sequence W^{*} is obtained and inverse affine transform is performed on this sequence, then the watermark information has been extracted according to a sequence of the binary pseudo-random p_i modulating the watermark. There are some fascinating advantages using SVD in digital image watermarking. First, singular values contain intrinsic algebraic image properties and corresponding pair of singular vectors reflect the geometrical feature of images. Second, singular values in a digital image are less affected if general image processing is performed. Third, the size of the matrices from SVD transformation is not fixed and can be a square or a rectangle.

Proposed watermarking scheme

Particle swarm optimization (PSO)

This section summarizes some basic structural components of PSO (Clerc and Kennedy, 2002; Kennedy and Eberhart, 1995; Mohammad et al., 2010). The basic idea of the classical PSO framework is the efficient exchange of information about the global and local best values. Primarily, the technique aims at maximizing or minimizing some constrained or unconstrained function by looking into the situational requirement. For achieving the desired objective, the technique depends upon a swarm of particles. Each particle in the swarm has some velocity and possesses some location. For example, if it is assumed that our goal is to optimize an objective function $f(r)$. Then each particle in the swarm will be examined in terms of its performance according to two views. From a set of potential solutions, each solution is assigned a randomized velocity, and particles. Now the

important feature of the approach is that each particle in the swarm flies in the D-dimensional problem space. The particles fly with a velocity which could be dynamically adjusted according to the flying velocities of the other particles forming the swarm. In other words it can be said that the approach concentrates over the position and the moving speed of the particle. Let us suppose that the location of the ith particle is represented as $X_i=[x_{i1}, x_{i2},\ldots, x_{iD}]$, where $x_{id} \in [l_d, u_d]$, $d \in [1,D]$. Id and ud are the lower and upper bounds for the dth dimension, respectively. The best previous position (which gives the best fitness value) of the ith particle is recorded and represented as $P_i=[p_{i1}, p_{i2},\ldots, p_{iD}]$, which is also called pbest . The location pg is denoted by gbest. The velocity of the ith particle is represented by $V_i=[v_{i1}, v_{i2},\ldots, v_{iD}]$ and the maximum velocity of the particles in the swarm can be represented as $V_{max}=[v_{max1}, v_{max2},\ldots, v_{maxD}]$. Therefore, the approach critically monitors the velocity and location of each particle in every single iteration. Finally, the particles move toward their respective pbest and gbest locations according to Equations 10 and 11, respectively:

$$v_{id}^{n+1} = v_{id}^{n} + c_1 r_1^{n}\left(p_{id}^{n} - x_{id}^{n}\right) + c_2 r_2^{n}\left(p_{gd}^{n} - x_{id}^{n}\right) \qquad (10)$$

$$x_{id}^{n+1} = x_{id}^{n} + v_{id}^{n+1} \qquad (11)$$

Where, c_1 and c_2 are two positive constants, called cognitive and social parameter, respectively; d=1,3,….,D; i=1,3,….,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,….,N denotes the iteration number, N is the maximum allowable iteration number.

Hybrid particle swarm optimization

In PSO, two reasons are responsible for converging prematurely of the swarm. First, for the global best of PSO, the underlying principle behind this challenge is that particles converge to a single point, which is on the line between p_{best} and g_{best} positions, but this point is not guaranteed for a local optimum. Second, the fast rate of information flow between particles results in the creation of similar particles without increasing the population diversity and the ability to have the PSO to avoid the local optima. Therefore, to overcome the limitations of PSO, the strategy of hybrid PSO with a local search method becomes a good idea such that PSO finds the possible solutions where the global optimum exists, and local search method employs a fine search to precisely find the global optimum. This kind of solution approach makes the convergence rate faster than the pure global search and prevents the problem of trapping to local optimums by pure local search.
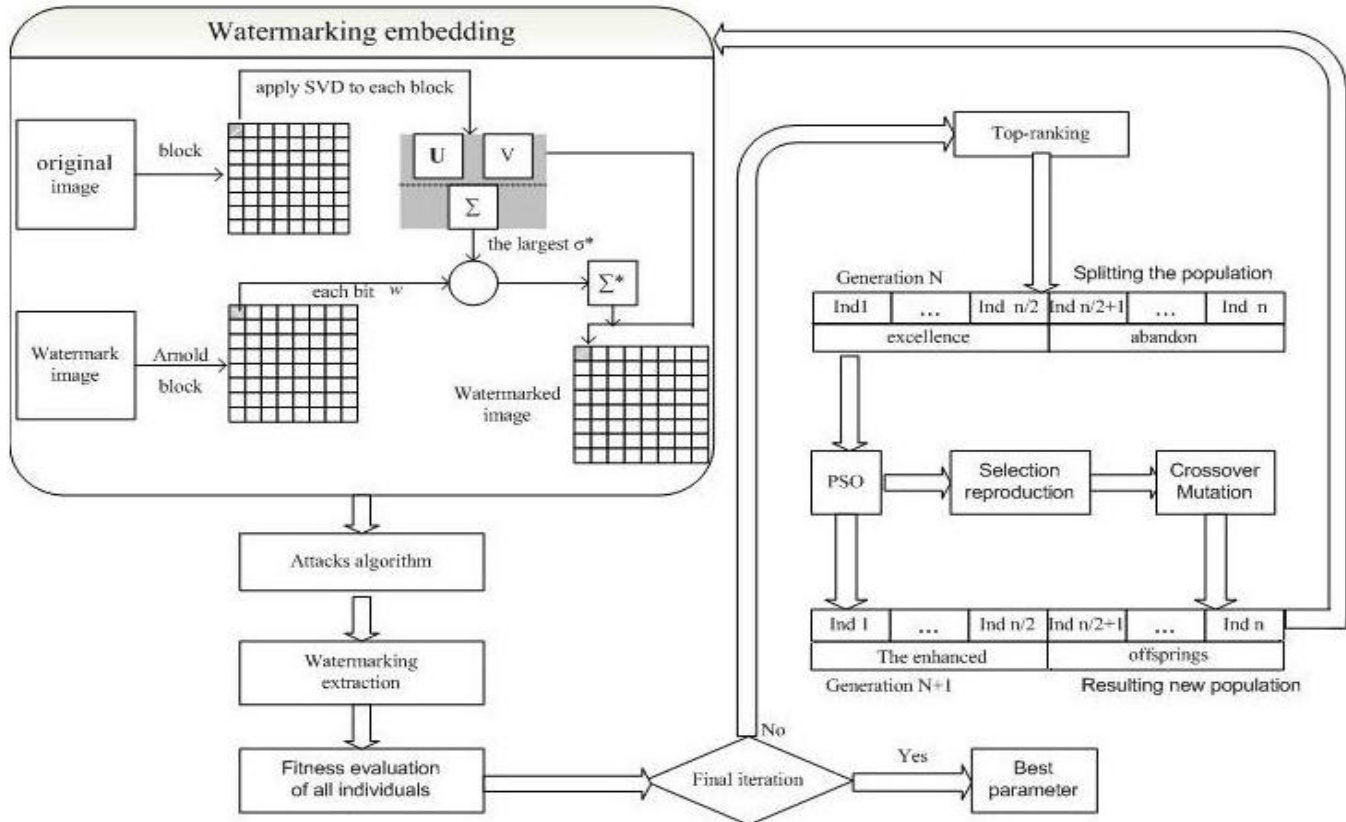
Figure 1. The proposed method (Watermarking Based On HPSO).

The HPSO algorithm is designed by employing crossover and mutation operators of GA (Pathak et al., 2009; Srinivas and Patnaik, 1994). Because the major advantages of the GA with respect to other optimization algorithms, such that, it is mainly related to their ability to prevent local minima and their independence from the initialization. Moreover, it works well in many research scopes and is an efficient algorithm that it is possible to improve the convergence ratio and to make a good choice of the algorithm parameters. Therefore, in each generation, the fitness function values of all the individuals are calculated in the same population, and then the half top ones of excellent performance are processed by PSO scheme initially. Instead of repro-ducing the half top ones directly to the next generation, crossover and mutation operators are performed on updated positions of the global best particles of PSO. By applying selection operation, it tends to be stochastic in nature for ensuring that the population diversity of possible solutions is maintained at a high level and for avoiding to converge on poor and incorrect solutions. And then the crossover and mutation operations are applied to selected chromosome with the their probability. Moreover, the tournament selection scheme is used, where two individuals are selected at random. Their fitness values are compared with the former better fitness value for

selecting the better one as one parent. The produced off-springs are expected to perform better than some of those in original population by updated individuals, and the weak-performed individuals will be kicked out from generation to generation. However, in opposition, PSO is adopted to update the top-ranking individuals on each generation for improving PSO's ability to constrain and control velocities. All swarm particles tend to move towards better positions, hence, the optimum solution can eventually be obtained through the combined effort of the whole population.

PARAMETERS SETTING

In the optimization process, the parameters are the scaling factors (α_1) which are obtained for optimal watermarking depending on both the transparency and the robustness factors. In the application of HPSO, in every generation, each member vector or particle in the population represents a possible solution to the problem, and hence, it is comprised of a set of scaling factors. Figure 1 illustrates briefly the flowchart of the watermark embedding technique by applying HPSO algorithm.

To start the optimization, HPSO is applied to randomly

produced initial solutions which is generated by a random number generator between 0 and 1. In the proposed scheme, for solving the optimization problem for multiple parameters, α in Equation 6 is embedded into the largest singular value of each blocked diagonal matrix and multiplied by each watermark bit. Therefore, all of α_1 represent the multiple scaling factors in all of blocks. After modifying the largest singular values of the blocked host image by employing the scaling factors, the watermarked images of the current generation are calculated according to the procedure of embedding watermark.

The strength of robustness of the watermark varies from application to application because of not all watermarking applications requiring robustness to all possible signal processing operations. The robustness of the proposed watermarking scheme is evaluated using the attacks that are commonly employed in literature. The evaluation of the objective function is done in the presence of well known attacks. For example, adding salt-pepper noise (0, 0.01), applying median filter (3×3), rotating (0.5) and doing JPEG compression (QF=40). Because of the flexibility of the developed system, the other attacking methods can easily be included to the system or replaced with those used in the HPSO optimization process.

The watermarks are computed from the attacked watermarked images using the extraction procedure given in above. We evaluate the performance of the watermark extraction by estimating the Normalized Correlation (NC)

$$NC = \frac{\sum_{i=1}^{i=m}\sum_{j=1}^{M}I(i,j)I'(i,j)}{\sum_{i=1}^{i=m}\sum_{j=1}^{M}I(i,j)^2} \tag{12}$$

where, I is the original watermark image, I' is the extracted watermark. The coefficient results of NC clearly demonstrate the good performance of the proposed method. The two-dimensional NC values are computed between the original and watermarked images ($NC_I = NC(I, I_W)$) and between the original watermark and the extracted ones ($NC_W = NC(W, W^*)$). Then, the normalized correlation values are utilized to compute the fitness value solution in the population (swarm) of HPSO. In every solution, the fitness value is computed depending on both the transparency(NC_I) and the robustness (NC_W) under certain attacks at each generation of an optimal process as discussed above.

For solving optimal embedding problem, a novel algorithmic framework is proposed via a forecasted feasibility of the approach to parameters evaluation. Instead of using traditional parameters summation evaluations (Aslantas, 2008, 2009), the multiplication is applied to the imperceptibility and robustness factors. When the predicted watermarked images are tested by serious distortions, the multiplicative algorithmic framework becomes more sensitive to the alteration between the two factors. For obtaining the optimal scaling factors, the maximum of objective value $\text{fitness}(i)$ can be calculated the values of NC_I and NC_W by

$$\text{fitness}(i) = NC_I \times \frac{1}{m}\sum_{i=1}^{m}NC_W \tag{13}$$

where NC_I is related to transparency measure and NC_W is related to robustness measure, $\text{fitness}(i)$ and m are the average of fitness value of the ith solution and the number of attacking methods, respectively. Having evaluated all strings in a generation (N) by top-ranking excellent performance in the fitness evaluation of all individuals, the strings that produced the bigger fitness values are selected for the new generation (N+1), according to the top half individuals of best performance, which are regarded as the excellent ones. The population of the new generation is then produced from these strings by using HPSO operators, which are constriction, crossover and mutation operators. These explained processes above are repeated until a given number of generations is exceeded.

The summary of HPSO-based watermarking procedures is as follows:

1. Initialize a population of particles with random positions and velocities on d-dimensions in the problem space;
2. Produce watermarked images using the solutions in the population by embedding process based- SVD;
3. Calculate the NC values between the host image and each watermarked image;
4. Apply the attacked functions on the watermarked images and extract out the watermarks from the distorted images using the extraction procedure previously describe. Calculate the NC values between the watermarks and the extracted ones according to four tested attacks;
6. For each particle, evaluate the desired optimization fitness function in d variables and rank the half of best performance individuals;
7. Update the velocity and position of the particle according to Equations 10 and 11, respectively:

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

and

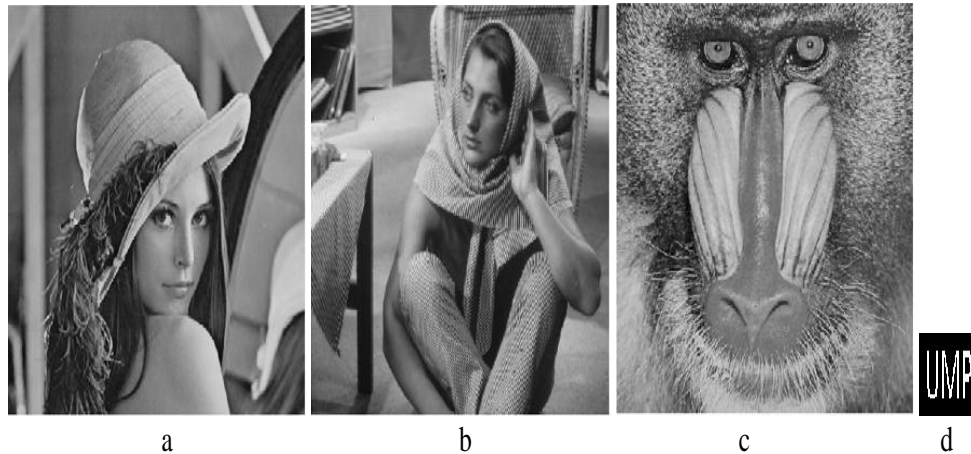$$x_{id}^{n+1} = x_{id}^{n} + v_{id}^{n+1}$$

Figure 2. The original image: (a) Lena (b) Barbara (c) Mandrill. and the original watermark (d).

8. Obtain offspring from applying crossover and mutation operators of GA to the gbest;

9. If the criterion is not satisfied, go to step 2. Otherwise, stop and obtain the results from the best position and fitness.

EXPERIMENTAL RESULTS

Experiment settings

In other to evaluate the performance of the proposed watermarking scheme, it is tested on the popular test gray-level images 256×256 Lena, Barbara and Mandrill. And a 32×32 binary image W_s is used as the watermark pattern consisting of 1024 bits, where $W_s = (w_{1 \times 1}, w_{1 \times 2}, \ldots, w_{32 \times 32},)$, as shown in Figure 2a to d. The host image is partitioned into blocks with 8×8 pixels and the largest singular value $\sigma_{i,j}^1$ from each block. To eliminate the correlation of watermark image pixels and enhance system robustness and security, the watermark can be pretreated by affine scrambling. The attacks that were utilized in the fitness evaluation process were: adding salt-pepper noise (0, 0.01), applying median filter (3×3), rotating (0.5) and doing JPEG compression (QF=40). Then, the same transforms were applied by both the original and watermarked image. In the representation of HPSO optimal solutions in the population, each string consists of 1024 variables. Each variable represents a possible value for each scaling factor. The 10 strings with highest fitness value were reserved for the new population (swarm) of the next generation. The number of generation for each experiment was set to 400. In GA operators, crossover rate and mutation rate are chosen at 0.03 and 0.6, repectively.

The performance of proposed scheme is the invisibility of the inserted watermark and the robustness of the method against various types of attacks and the experimental results are compared with the corrected SVD-based scheme of (Aslantas, 2008) and also the SVD-based PSO scheme. Several experimental implementations were done by the software of MATLAB 7.10.0. All the implementations were developed using a computer with processor AMD torsion X2 of 64 bits that works to a frequency of a clock of 1800MHz, 2 GB of RAM Memory and Windows Vista Ultimate operating system.

Experimental results of imperceptibility

Normally, the imperceptibility is checked by investigating both the watermarked and the original image. The Normalized Correlation (NC_I) of a watermarked image is determined by two main factors. On the one hand, given fixed scaling factors or watermark strength, the number of bits to be embedded determines the NC_I of the watermarked image. The less bits embedded, the higher value of NC_I, and vice versa. On the other hand, given a fixed number of bits to be embedded, the strength of scaling factors controlls the value of NC_I. Larger scaling factors leads to a stronger watermark, but results in a lower NC_I, and vice versa.

Figure 3 presents that the optimal watermark-embedding technique is imperceptible truly and there is no difference between the original images and watermarked ones perceptually in the proposed scheme. The proposed HPSO watermarking scheme has the visual performace better than the corrected SVD-based scheme of (Aslantas, 2008) and also the SVD-based PSO scheme. In the proposed scheme, scaling factors are chosen optimally using objective function such that the results of NC_I are limited over 0.97 in Table 1, which guarantees a good watermark transparency compared
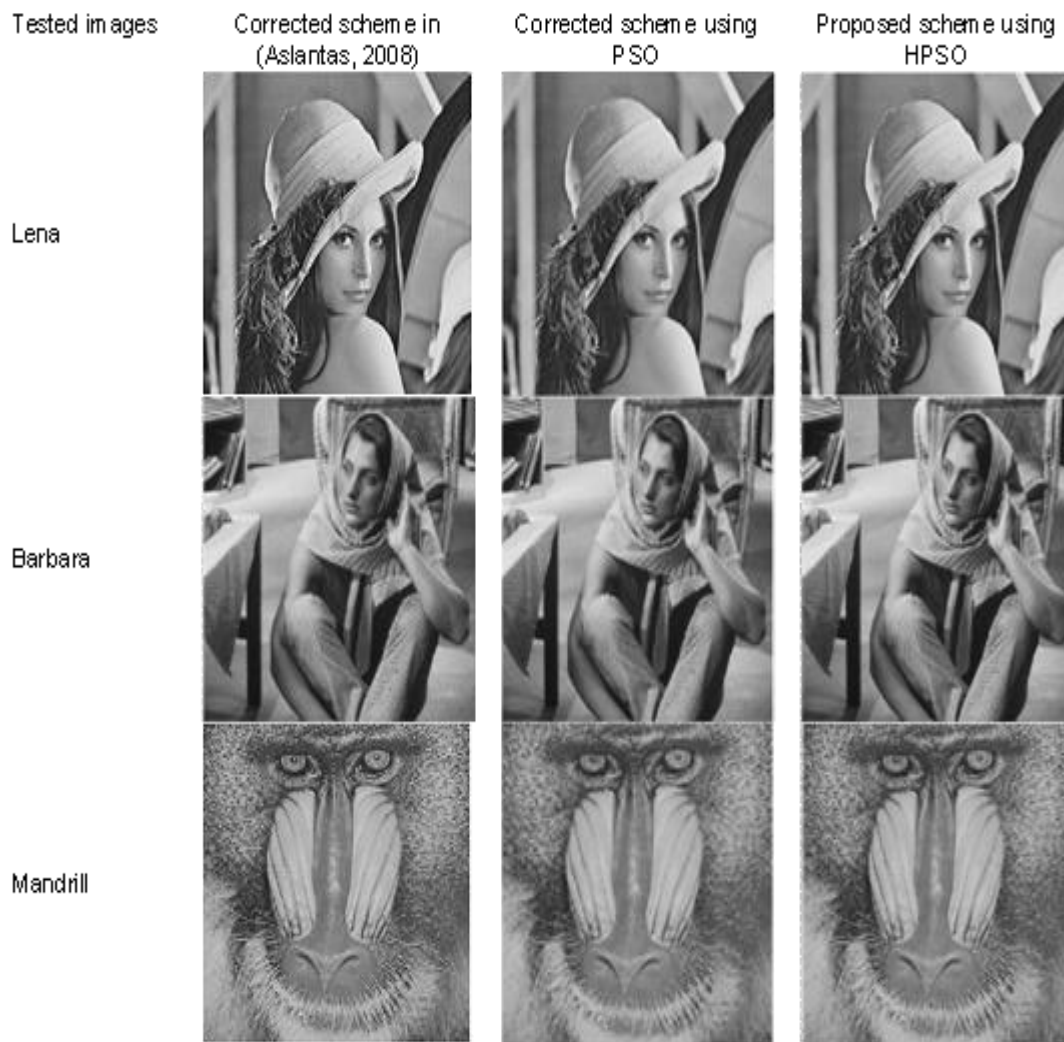
Figure 3. The imperceptibility comparation of watermarked images.

with others.

Experimental results of robustness

Distorted images (Lena as an example) after a variety of attacks and corresponding extracted watermarks are illustrated in Figure 4. In order to illustrate the robustness of the proposed watermarking scheme, several common image processing and geometric attacks was applied. The attacked operations are Rotation (RT) (in degree 10), Resize (RS) (100 to 50 to 100%), Dithering (DT), Gaussian noise (GN) (0,0.0.1), Tampering, Cropping (CP)(10%), JPEG compression (QF=40), Lowpass filtering (LP)(3 × 3) and Salt and pepper noise (SP) (0,0.0.1). From the experimental results, it is shown that, even if the watermarked image has undergone several severe common image processing and geometric

distortions, the extracted watermark is still recognizable.

In Table 1, NC_W is used to measure the similarity between the original watermark and the extracted ones. For the three images, the same experiments were also carried out with constant scaling factors ranging from 0.10 to 0.30 with the interval of 0.05. For the comparison of NC values, the results of constant scaling factors are also illustrated in Table 1. As can be seen from Table 1, the larger the constant scaling factor the stronger the robustness. In contrast, the smaller the constant scaling factor the weaker the robustness. The results of the multiple scaling factors obtained by HPSO reveals that robustness performances of the proposed approach is superior to the other similar approaches.

Computational efforts reflecting

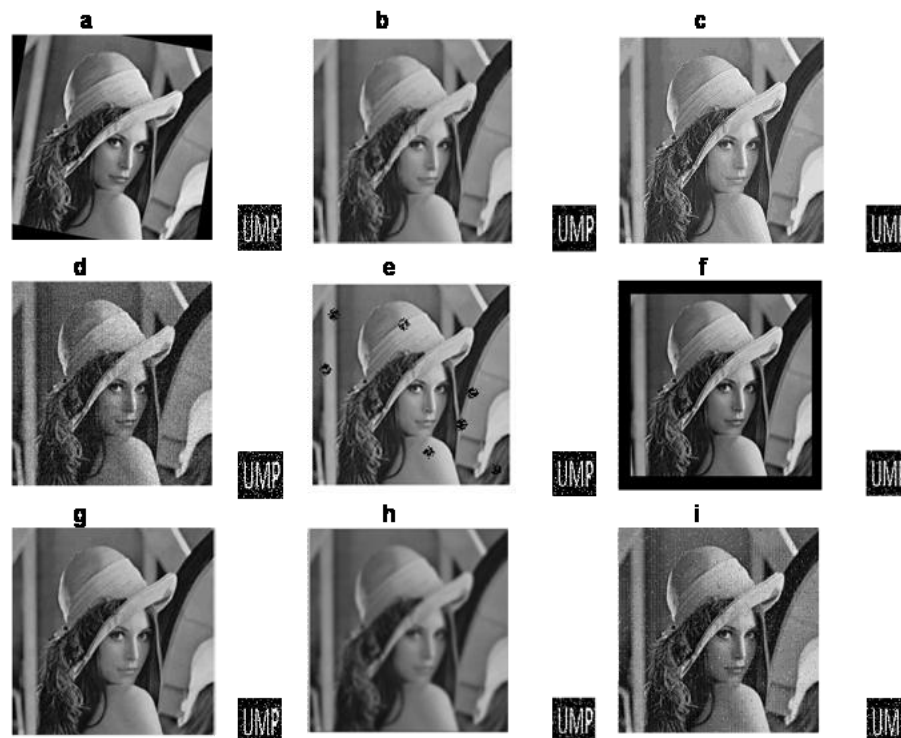The fitness values of various sizes of population are

Figure 4. Experiment results of the attacked watermarked images and extracted watermarks using (a) Rotation (RT) (in degree 10) (b) Resize (RS) (100 to 50 to 100%) (c) Dithering (DT) (d) Gaussian noise (GN) (0, 0.01) (e) Tampering (TP) (f) Cropping (CP) (10%) (g) JPEG compression (QF 40) (h) Low pass filtering (LP) (3 × 3) (i) Salt and pepper noise (SP) (0, 0.01).

Table 1. NC value obtained by scaling factors (SF) of the three images.

		NC_I	NC_W								
			RT	RS	DT	GN	TP	CP	JPEG	LP	SP
Lena	HPSO SFs Constant SFs		0.7554	0.8127	0.8429	0.7716	0.9804	0.8029	0.9524	0.7849	0.8916
	0.30	0.9785	0.7642	0.8274	0.8464	0.7754	0.9842	08165	0.9231	0.7783	0.8945
	0.25	0.9822	0.7255	0.8129	0.8425	0.7702	0.9817	0.8069	0.9171	0.7541	0.8917
	0.20	0.9870	0.6923	0.8045	0.8401	07682	0.9749	0.7812	0.9126	0.7217	0.8762
	0.15	0.9913	0.6673	0.7687	0.8329	0.7537	0.9638	0.7691	0.8945	07045	0.8519

Table 1. Contd.

		0.10	0.9958	0.6157	0.7583	0.8310	0.7512	0.9526	07537	0.8764	0.6621	0.8431
Barbara	**HPSO**	**SFs Constant SFs**		0.7793	0.7122	0.7792	0.7690	09602	07949	0.9035	0.7721	0.8264
		0.30	0.9765	0.7846	0.7289	0.7811	0.7743	0.9644	0.7967	0.9069	07756	0.8314
		0.25	0.9817	0.7723	0.7252	0.7657	0.7682	0.9521	0.7873	0.9004	0.7675	0.8326
		0.20	0.9872	0.7487	0.7116	0.7483	0.7565	0.9600	0.7646	0.8935	0.7521	0.8259
		0.15	0.9934	0.7211	0.7101	0.7364	0.7529	09517	0.7515	0.8877	0.7401	0.8177
		0.10	0.9969	0.6825	0.7066	0.7295	0.7465	0.9483	0.7394	0.8861	0.7350	0.8111
Mandrill	**HPSO**	**SFs Constant SFs**		0.7648	0.7866	0.7826	0.7823	0.8815	0.7855	0.8711	0.7687	0.8969
		0.30	0.9778	0.7705	0.7843	0.7925	0.7872	0.8676	0.7678	0.8705	0.7667	0.8960
		0.25	0.9837	0.7561	0.7839	0.7809	0.7817	0.8872	0.7744	0.8613	0.7653	0.8877
		0.20	0.9862	0.7272	0.7742	0.7615	0.7737	0.8763	0.7649	0.8527	0.7562	0.8791
		0.15	0.9937	0.6946	0.7656	0.7523	0.7696	0.8794	0.7474	0.8433	0.7481	0.8673
		0.10	0.9981	0.6537	0.7558	0.7328	0.7418	0.8611	0.7213	0.8429	0.7483	0.8579

Table 2. Fitness values for different population sizes (PS).

Population size	50	75	100	125	150
Fitness$_{GA}$	0.6437	0.6646	0.6934	0.7326	0.7211
Fitness$_{DE}$	0.6616	0.6857	0.7342	0.7636	0.7392
Fitness$_{HPSO}$	0.7015	0.6982	0.7494	0.7856	0.7797

displayed in Table 2 using SVD-based GA, PSO and HPSO watermarking algorithms. Algorithms are worked similarly with different runs and are not dependent on the random starting population. It is indicated that the proposed scheme is carried out optimal results without the population size beyond 125. Compared with the other similar optiaml approaches, the proposed scheme is more effective one for economizing computional resources. In Figure 5, it is shown that the different fitness values are obtained from different population sizes, it is distinct that the important improvement of the proposed scheme is superior to the other optimal approaches.

Conclusions

Obtaining the highest possible robustness without losing the transparency is still one of the most challenging issues in image watermarking techniques. This paper presents a novel optimal robust image watermarking technique based on HPSO which is robust against a variety of common image-processing attacks and some geometric attacks. The watermark embedding and watermark extraction issues can be treated as an optimal problem for robustness evaluation of watermarking techniques. For giving rise to the smallest degradation after removing the watermark under selected pattern attacks, the processes of GA, PSO and HPSO optimal watermarking methods are analyzed. By the comparison of GA and PSO, the proposed hybrid scheme is run for the estimation of optimal scaling factors to be assigned to each attack in order to detect the attacked watermark perceivably closest to the original one and simultaneously maintain the transparency of host grey-level image, which
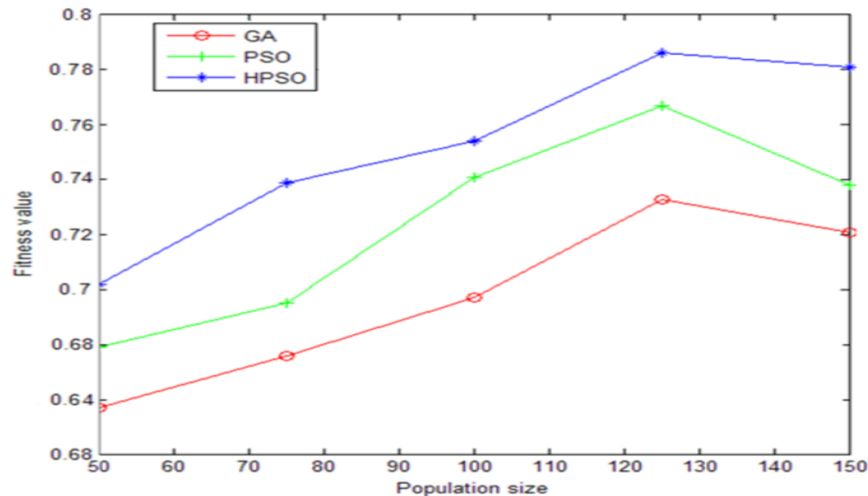
Figure 5. Fitness values for different population sizes.

takes advantage of their merits and eliminates their drawbacks. To adjust multiple parameters, GA and PSO obtained very good results and was very little, the difference between them is that when the number of variables is small, however, the HPSO is a more complex method but is more reliable because is a hybrid method in terms of the optimal process of insertion-extraction watermarking. The experimental results demonstrates that the watermark of the proposed technique has the superiority performance under various attacks without losing the transparency among those compared approaches.

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