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Optimized gray-scale image watermarking using DWT–SVD and Firefly Algorithm

Anurag Mishra [a], Charu Agarwal [b,*], Arpita Sharma [c], Punam Bedi [b]

[a] Department of Electronics, Deendayal Upadhyay College, University of Delhi, Delhi, India
[b] Department of Computer Science, University of Delhi, Delhi, India
[c] Department of Computer Science, Deendayal Upadhyay College, University of Delhi, Delhi, India

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ABSTRACT

This paper presents an optimized watermarking scheme based on the discrete wavelet transform (DWT) and singular value decomposition (SVD). The singular values of a binary watermark are embedded in singular values of the LL3 sub-band coefficients of the host image by making use of multiple scaling factors (MSFs). The MSFs are optimized using a newly proposed Firefly Algorithm having an objective function which is a linear combination of imperceptibility and robustness. The PSNR values indicate that the visual quality of the signed and attacked images is good. The embedding algorithm is robust against common image processing operations. It is concluded that the embedding and extraction of the proposed algorithm is well optimized, robust and show an improvement over other similar reported methods.

1. Introduction

With the increased growth in internet usage, digital images can be spread worldwide on a single click of the mouse. This leads to vulnerability of digital images and generate a logical question on its copyright. There are various information security techniques that can handle the copyright issue. Digital image watermarking is one such powerful method to tame copyright violation of the digital content. It is also frequently used for content authorization. It is the process of embedding digital information or watermark (such as a logo image or a secret image) into the host image in such a manner that the embedded watermark can be detected or extracted later from the signed image without degrading the extracted watermark (Cox, Kilian, Leighton, & Shamoon, 1997; Liu & Tan, 2002a; Abdallah, Ben Hamza, & Bhattacharya, 2007).

In this regard, two major criteria are mandatory fulfilled. These are (1) imperceptibility of embedded watermark and (2) robustness of the watermark embedding scheme. Based on these criteria, watermarking techniques can be broadly classified into three groups: robust, fragile and semi-fragile (Cox et al., 1997). Robust watermarking is designed to be resistant against attacks that attempt to remove or destroy the watermark without degrading the visual quality of the watermarked image significantly. This is typically employed for copyright protection and ownership verification. Conversely, fragile watermarking is employed to ensure the integrity and image authenticity rather than verifying the actual ownership. It is designed to detect any unauthorized modification in such a way that slight modifications or tampering with the watermarked image will alter or destroy the watermark. Semi-fragile watermarking combines the properties of fragile and robust watermarking in order to detect unauthorized manipulations while still being robust against authorized manipulations. Semi-fragile watermarking can also be used for authentication.

It has been observed that fragile watermarking is achieved if the embedding is carried out in the spatial domain image. Here, the watermark is directly inserted into the cover image by altering the pixel values (Nikolaidis & Pitas, 1998; Liu & Chen, 2001). It leads to ease implementation and low cost of operation but are generally not robust to affine transformations and image processing attacks. In contrast, frequency domain methods transform the image into the frequency domain and then modify its frequency coefficients to embed the watermark. This leads to robust watermark embedding. There are many transform domain watermarking techniques such as discrete cosine transforms (DCT) (Briassouli & Strintzis, 2004; Patra, Phua, & Bornand, 2010; Hernandez, Amado, & Perez-Gonzalez, 2000), singular value decomposition (SVD) (Jain, Arora, & Panigrahi, 2008; Liu & Liu, 2008; Liu & Tan, 2002b) and discrete wavelet transforms (DWT) (Xianghong, Lu, Lianjie, & Yamei, 2004; Ohnishi & Matsui, 1996; Meerwald & Uhl, 2001; Barni, Bartolini, & Piva, 2001; Dawei, Guanrong, & Wenbo, 2004).

* Corresponding author. Tel.: +91 9891994775.
E-mail addresses: anurag_cse2003@yahoo.com (A. Mishra), agarwalcharu2@rediffmail.com (C. Agarwal), arpt1_mishra1@yahoo.com (A. Sharma), punambedi@gmail.com (P. Bedi).

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Frequency domain analysis is used to figure out the possible locations to embed watermark coefficients to ensure greater robustness of the embedding algorithm. It is well known that human eyes are more sensitive to low frequency and mid frequency band coefficients. Therefore, transform domain techniques are found to work well if the watermarks are embedded within the low frequency coefficients of the image (Cox et al., 1997; Nikolaidis & Pitas, 1998). Moreover, it has been reported that among the transform domain methods, DWT is more suitable for achieving robust watermarking and imperceptible leading to good visual quality signed image.

For the past many years, the singular value decomposition (SVD) is used as a new method for watermarking. It provides a general, characteristic view on changes of an image and its structural information which is crucial in prediction of the image quality. It is noted that singular vectors denote clearer physical meaning for representing structural information. Modifications in singular vectors are relate to that in singular values which primarily represent the image luminance. We use DWT–SVD hybrid transform in the present work to carry out watermark embedding.

Liu and Liu (2008) introduced the SVD based watermarking algorithm. In this algorithm, they compute singular values of the host image and then modify them by adding the watermark. They again apply SVD transform on the resultant matrix for finding the modified singular values. These singular values are combined with the watermark to get the watermarked image. For watermark extraction, an inverse process is used. SVD based watermarking has been proposed by various researchers (Alexander, Scott, & Ahmet, 2005; Bhatnagar & Raman, 2009; Chandra, 2002a; Ganic & Eskicioglu, 2004; Ghazy, El-Fishawy, Hadhoud, Dessouky, & El-Samie, 2007; Huang & Guan, 2004) using a single (constant) value of scaling factor. Li, Yuan, and Zong (2007) proposed a hybrid DWT–SVD domain watermarking scheme considering human visual system properties. They decompose the host image into four sub-bands and apply SVD to each sub-band and embed singular values of the watermark into these sub-bands. Chandra (2002b) describes a method by embedding singular values of the watermark to the singular values of the entire image. First, singular values of the host image and watermark are computed, and then the singular values of the watermark are magnified and added to those of the host image.

It is a fact that conventional research on image watermarking is limited to the use of standard mathematical formulations such as DCT, DWT, SVD and their hybrid variants such as DCT–DWT, DCT–SVD and DWT–SVD. The watermark is embedded within the host images using mathematical equations which traditionally use watermark embedding strength based on single scaling value. The embedding strength or the scaling factor is the amount of modification caused by the watermark in the original medium. In digital image watermarking, generally, a single or a constant value of the scaling factor is used to embed watermark within the entire host image. The local distribution of the original image is not considered during the process of embedding. However, this type of embedding can lead to some undesirable visible artifacts in the watermarked image (Cox et al., 1997; Li et al., 2007). These deformities are noticed majorly in smooth regions because smooth regions of an image are more sensitive to noise. In order to reduce these deformities, the scaling factor should be decreased in the plain regions which in turn affect the robustness of the embedding process. In other regions, if the scaling factor is increased beyond a certain limit, this may lead to visible distortions within the signed image. Thus the selection of scaling factor has become an issue of tradeoff between imperceptibility and robustness. Cox et al. (1997) have also argued that a single scaling factor may not be applicable for perturbing all the coefficients of cover image as different spectral components may exhibit more or less tolerance to modification. Instead, they suggest using multiple scaling factors (MSFs) or multiple values of scaling factors. However, the main problem is to identify optimal values of the MSFs to obtain the best results. Presently, image watermarking has acquired multi-dimensional status in the multimedia research paradigm. Several soft computing techniques have been used to optimize the visual quality of signed images and robustness of the embedding algorithm. Robustness is evaluated after extracting watermarks and establishing similarity between the set of coefficients originally created by ones recovered after extraction. In this direction, a lot of research activities are going on using techniques such as support vector regression (SVR) using different kernel functions (Tsai, Jhuang, & Lai, 2012). Similarly, real time image watermarking is best handled using a newly developed single layer feed forward (SLFN) neural network commonly known as extreme learning machine (Anurag Mishra, Goel, Singh, Chetty, & Singh, 2012). It is found that these results are even better optimized after having used the human visual system (HVS) model. Many researchers have also used the HVS model along with Fuzzy Inference System (FIS) to obtain better results (Motwani, Motwani, & Harris, 2009; Motwani and Harris, 2009.

In addition to this, evolutionary algorithms such as – Particle Swarm Optimization (PSO) (Fındık, Babaŏglu, & Ülker, 2010; Run, Horng, Lai, Kao, & Chen, 2012; Wang, Lin, & Yang, 2011), Genetic Algorithm (GA) (Kumsawat, Attakitmongcol, & Srikaew, 2005; Shih & Wu, 2005; Shieh, Huang, Wang, & Pan, 2004), Bacterial foraging (Huang, Chen, & Abraham, 2010) have been extensively used for image watermarking. Most existing evolutionary techniques are used to identify coefficients of the image in transform domain to embed the watermarks (Wang et al., 2011; Shieh et al., 2004; Huang et al., 2010). As mentioned above, the problem of finding the optimal values of multiple scaling factors (MSFs) can be solved by combining evolutionary techniques with the transformed techniques (Lai, 2011; Muhammad Ishtiaq, Sikandar, Jaffar, & Khan, 2010; Loukhaoukha, Chouinard, & Taieb, 2011). Lai (2011) have used the tiny genetic algorithm (Tiny-GA) with SVD to find values of MSFs. However, it is pointed out by Loukhaoukha (2013) that this algorithm (Lai, 2011) causes false positive detection, even if the embedded watermark is different or nonexistent.

Ishtiaq et al. (2010) have applied PSO technique to find the multiple scaling factors in the DCT domain. They use PSNR as the objective function to evaluate each particle. The major drawback of this algorithm is that it only focuses on the visual quality of watermarked image without taking into account the robustness. Loukhaoukha et al. (2011) have utilized multi-objective ant colony optimization (MOACO) in LWT–SVD domain to find the values of MSFs. Their objective function is an exponential weighted formulation given by Eq. (1).

$$F_{obj}(X) = \sum_{i=1}^{T+2} (e^{p \cdot w} - 1) e^{p(F(X) - F_0)} \qquad (1)$$

where p, w and F_0 are the positive constants, $F(X)$ is the vector of objective values and T is the number of selected image processing operations. They claim that the proposed MOACO-based MSFs watermarking scheme outperforms different SSF watermarking schemes in terms of imperceptibility and robustness. In this paper, we propose Firefly based novel image watermarking scheme which optimizes MSF to produce best results. We compare our results with those published by Ishtiaq et al. (2010) and Loukhaoukha et al. (2011).

1.1. Motivation

It is clear from the survey of the papers presented in the previous section that the performance of the embedding scheme is improved upon by using hybrid transform such as DWT–SVD. Secondly, nearly all evolutionary techniques optimally generate MSFs rather than relying on SSF based embedding strength.

Recently, a newly developed optimization tool based on swarm intelligence cum meta-heuristic technique known as a Firefly Algorithm (FA) is developed by Yang (2008). This tool is different from its other counterparts such as GA, PSO and few other meta-heuristic techniques. Many researchers have employed FA for different applications and found that it outperforms other meta-heuristic techniques such as PSO and GA. Horng and Jiang (2010) have employed this algorithm for multilevel image thresholding application. They proposed a new Multilevel Entropy Thresholding (MET) algorithm based on FA commonly known as MEFFT. They claim that their scheme can search for multiple thresholds which are very close to the optimal ones examined by the exhaustive search method. They also claim that as compared to PSO and hybrid cooperative-comprehensive learning based PSO (HCOCLPSO) algorithm, the segmentation results obtained by MEFFT algorithm are significantly improved and the computation time is the least.

Zhang and Wu (2012) have employed the FA for image registration application. They said that the image registration can be simplified as an optimization problem in which the input variables contain two translational parameters and one rotational parameter. The objective function is the Normalized Cross Correlation (NC). They have shown that their FA based method can achieve the closest solution to the actual spatial transformation parameters compared to GA, PSO, and Ant Bee Colony (ABC). Senthilnath, Omkar, and Mani (2011) have employed the FA for data clustering application. They conclude that the FA is an efficient, reliable and robust method which can be applied successfully to generate optimal cluster centers.

In the present paper, we, therefore, use this evolutionary technique to carry out an altogether different application – watermark embedding and extraction within gray-scale host images. To the best of our information, this technique has not been reported by any researcher for this purpose worldwide.

1.2. Research focus and contribution

This research work focuses on optimizing the trade-off between the twin parameters of image watermarking: imperceptibility and robustness. We propose a new image watermarking scheme based on the hybrid transform: DWT and SVD; and identifying multiple scaling factors by using a novel evolutionary technique named as FA. In this case, the objective function used by this algorithm is a linear combination of PSNR and normalized cross-correlation (NC). The NC is a metric to determine the robustness and therefore we select eight different image processing operations as attacks to evaluate it. These are: JPEG compression (Q = 95), salt and pepper noise (5%), Gaussian filtering (filter aperture = 3 × 3), sharpening (aperture = 0.2), histogram equalization (with 64 discrete gray levels), scaling (256 → 512 → 256), gray-scale quantization (1-bit) and Cropping by dividing the image into 9 equal blocks, replacing the central block with zeros. This firefly evolutionary technique is used to implement gray-scale image watermarking for the first time to the best of our information. We compare the results obtained with this watermarking scheme for single scaling factor (SSF) and multiple scaling factors (MSFs). We find that MSFs based watermarking outperforms SSF based watermarking in terms of imperceptibility and robustness. We also compare proposed MSFs based technique with other similar technique (Ishtiaq et al., 2010; Loukhaoukha et al., 2011). Experimental results show that the proposed watermark embedding and extraction scheme outperforms other scheme for all image processing operations except sharpening and cropping. We attribute better results for robustness obtained by us to better optimization of MSFs using FA. The PSNR values indicate that the visual quality of the signed and attacked images is good. The embedding algorithm is robust against common image processing operations. This paper provides another scope to identify the optimal watermark strength by using FA. The remaining paper is organized as follows: Section 2 describes the FA and its pseudo-code. Section 3 describes DWT–SVD based watermark embedding and extraction algorithm using SSF. The issue of MSFs with respect to imperceptibility (PSNR) and robustness (NC) is discussed in Section 4. The optimization of MSFs using an objective function of FA and its use to embed and extract the watermark is discussed in Section 5. Section 6 presents experimental results and its analysis. The results are concluded in Section 7. Section 8 gives list of published work referred in this paper.

2. Firefly Algorithm

The Firefly Algorithm (FA) was first developed by Yang (2008) at Cambridge University. This is a new swarm intelligence optimization technique and is inspired by flashing light of fireflies. Two basic functions of the flash light are to attract mating partners and to attract potential prey. FA is based on the assumption that solution of an optimization problem can be perceived as fireflies whose "brightness" is proportional to the value of its objective function within a given problem space.

In the FA, there are three idealized rules:

(1) All fireflies are unisexual, so that one firefly will be attracted to other fireflies regardless of their sex.
(2) Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less brighter one will move towards the brighter one and.
(3) If there are no fireflies brighter than a particular firefly, it will move randomly.

In formulating the FA there are two important issues: – the variation of light intensity and formulation of the attractiveness. The attractiveness of a firefly is determined by its brightness which is proportional to the encoded objective function.

For maximization, the brightness of a firefly at a particular location $\mathbf{x}$ is proportional to the objective function. However, the attractiveness β is relative, it will vary with the distance $r_{i,j}$ between the firefly i and firefly j. It also varies with the degree of light absorption by the medium (air).

Yang (2008) used a Cartesian distance $r_{i,j}$ where i and j are two individual fireflies at location $\mathbf{x_i}$ and $\mathbf{x_j}$ respectively as given by Eq. (2).

$$r_{i,j} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{c}(x_{i,k} - x_{j,k})^2} \tag{2}$$

where $x_{i,k}$ is the kth component of the spatial coordinate x_i of ith firefly.

For a 2-D case, $r_{i,j}$ is given by Eq. (3).

$$r_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{3}$$

The attractiveness β of a firefly is determined by using Eq. (4).

$$\beta \leftarrow \beta_0 e^{-\gamma r_{i,j}} \tag{4}$$

where β_0 is the attractiveness at $r_{i,j}$ = 0 and γ is the light absorption coefficient of the medium.

The movement of a firefly i is attracted to another more attractive (brighter) firefly j and is given by Eq. (5).

$$x_i \leftarrow x_i + \beta_0 e^{-\gamma r_{i,j}}(x_j - x_i) + \alpha u_i \tag{5}$$

where the random walk parameter u_i is evaluated by Eq. (6).

$$u_i = \left(\text{rand}\,1 - \frac{1}{2}\right) \tag{6}$$

If there are no fireflies brighter than a particular firefly i with maximum objective value then i will move randomly according to the Eq. (7).

$$x_{i^{\max}} \leftarrow x_{i^{\max}} + \alpha\ u_{i^{\max}} \tag{7}$$

In this case the random walk parameter $u_{i^{\max}}$ is evaluated by Eq. (8)

$$u_{i^{\max}} = \left(\text{rand}\,2 - \frac{1}{2}\right) \tag{8}$$

where $\text{rand}\,1 \approx U(0,1)$ and $\text{rand}\,2 \approx U(0,1)$ are random numbers obtained from uniform distribution. The brightness of the firefly is affected or determined by the objective function $f(x)$. Listing 1 gives algorithm for firefly optimization.

Listing 1: Firefly algorithm for maximum optimization
Input:
Define objective function $f(x)$, $x = [x_1, x_2, \ldots, x_d]^T$
Generate initial population of fireflies $x_p (p = 1, 2, \ldots, n)$
Define α, β_0, maximum generation number (ML) and γ
Output: The best solution $x_i^{\max}$ with the largest objective function value
Begin
while ($t < ML$)
for $p = 1$: *n all n fireflies*
for $q = 1$: *n all n fireflies*
if $f(x_p) < f(x_q)$, *Move firefly p towards q*; end if
Attractiveness varies with distance r via exp $[-\gamma r]$
Evaluate new solutions and update objective function
end for q
end for p
Rank the fireflies and find the current global best $x_p^{\max}$
end while
End

---

3. DWT–SVD based watermarking algorithm

To study the effect of scaling factor on PSNR and normalized cross-correlation $NC(W, W')$ value the following DWT–SVD based watermarking algorithm is used in the present work. The signed images are examined for visual quality by PSNR given by Eq. (9). A watermark is extracted and $NC(W, W')$ parameter where W and W' being original and recovered watermarks respectively is computed by Eq. (10).

$$\text{PSNR} = 10\log_{10}\left(\frac{I_{\max}^2}{\text{MSE}}\right) \tag{9}$$

where $I_{\max}$ is the maximum possible pixel value of the image I and MSE is the mean square error.

$$NC(W, W') = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}[W(i,j) \cdot W'(i,j)]}{\sum_{i=1}^{m}\sum_{j=1}^{n}[W(i,j)]^2} \tag{10}$$

3.1. Watermark embedding algorithm

We consider the host image I of size $N \times N$ and the watermark W of size $m \times m$. The embedding scheme is given in Listing 2.

3.1.1. Listing 2: embedding algorithm

Step1. Apply 3 level DWT using HAAR filter on the host image I to obtain LL3 sub-band of size $m \times m$.
Step2. Apply SVD on LL3 sub-band coefficients of the host image obtained in step1 by using Eq. (11) and hence obtain S

$$[U, S, V] = \text{SVD(LL3)} \tag{11}$$

Step3. Apply SVD on the watermark (W) using Eq. (12) and identify the singular values (S_w)

$$[U_w, S_w, V_w] = \text{SVD}(W) \tag{12}$$

Step4. Embed S_w into S values using the formula given by Eq. (13) (Loukhaoukha et al., 2011)

$$S' = S + \delta * S_w \tag{13}$$

where δ is the single scaling factor which controls the tradeoff between imperceptibility and robustness of the proposed watermarking scheme.

Step5. Compute the modified LL3 sub-band coefficients using Eq. (14)

$$\text{LL3}' = U * S' * V^T \tag{14}$$

Step6. Apply inverse 3-level IDWT to obtain the signed image I'.

3.2. Watermark extraction algorithm

The embedded watermarks are recovered from signed images. The extraction is carried out by applying DWT–SVD combination again to signed images. The extracted watermark is denoted by W'. The watermark extraction algorithm is given in Listing 3.

3.2.1. Listing 3: extraction algorithm

Step1. Apply 3 level DWT using HAAR filter on the host image I and signed image I' to obtain LL3 and LL3′ sub band coefficients of size m x m respectively for the two images.
Step2. Apply SVD on the LL3 and LL3′ sub-band coefficients using Eq. (15) and (16) to obtain the singular values S and S' respectively

$$[U, S, V] = \text{SVD(LL3)} \tag{15}$$

$$[U', S', V'] = \text{SVD(LL3}') \tag{16}$$

Step3. Compute the singular values of the watermark using the formula given by Eq. (17)

$$S'_w = (S' - S)/\delta \tag{17}$$

Step4. Recover the extracted watermark image using the formula given by Eq. (18)

$$W' = U_w * S'_w * V_w^T \tag{18}$$

4. Examining trade-off between imperceptibility and robustness using scaling factor

Cox et al. (1997) have argued that a single scaling factor (SSF) may not be applicable for perturbing all the coefficients of the cover image in transform domain. This is due to the fact that different spectral components may exhibit different tolerance to the induced modification. Therefore, they stress upon the use of multiple scaling factors (MSFs) instead of a SSF to embed the watermark energy into the host image. They further said that the determination of MSFs might depend on the type and intensity of the image processing attack used.

Loukhaoukha et al. (2011) have used both SSF and MSFs in their experimental simulation. They argue that determination of the optimal values of MSFs for watermarking is an optimization problem. They optimize the determination of MSFs using multi-objective ant colony optimization (MOACO) method. They particularly use this method to improve visual quality and to enhance the robustness of their watermarking algorithm. In the present paper, we examine the trade-off between the imperceptibility (PSNR) and robustness ($NC(W, W')$) first using single scaling factor δ. The variation of $NC(W, W')$ vs. δ and the variation of PSNR vs. δ for Lena image are analyzed respectively in Section 4.1 and Section 4.2.

4.1. Effect of single scaling factor (SSF) over $NC(W, W')$ values for attacked Lena signed images

We first study the variation of $NC(W, W')$ with respect to single scaling factor (δ). The plot of $NC(W, W')$ w.r.t. δ is given in Fig. 1. It is clear from this figure that $NC(W, W')$ values vary only between the range of $\delta = 0.005$–0.06. Beyond $\delta = 0.06$, the $NC(W, W')$ values get stabilized. This is specifically true for all attacks barring sharpening, histogram equalization and cropping. For sharpening, histogram equalization and cropping attacks, the $NC(W, W')$ values with respect to δ are throughout constant. Thus, it is concluded that for the attacks used by us in this simulation, the range of $\delta = 0.005$–0.06 is an appropriate range to determine MSFs based on type and intensity of the considered attack. We therefore use this range for δ for all our future computations. Our findings are thus, corroborated with the analysis presented by Cox et al. (1997) in their paper.

4.2. Effect of single scaling factor (SSF) over PSNR for attacked Lena signed images

To examine the effect of scaling factor on visual quality of attacked Lena image, we plot its corresponding computed values as a function of δ. The number and types of attacks are specified in Section 1. This plot is depicted in Fig. 2. It is clear that PSNR and δ are inversely proportional to each other only for the signed image within the range $\delta = 0.005$–0.06. Beyond $\delta = 0.06$, the PSNR is constant w.r.t. δ. Moreover, for all attacked images, the PSNR is constant with respect to δ. This indicate that PSNR contributes more towards signed image only while $NC(W, W')$ is found to be a dominating factor both for watermark embedding and image processing attacks applied over the signed image. It is clear from this discussion that any objective function used to optimize water-

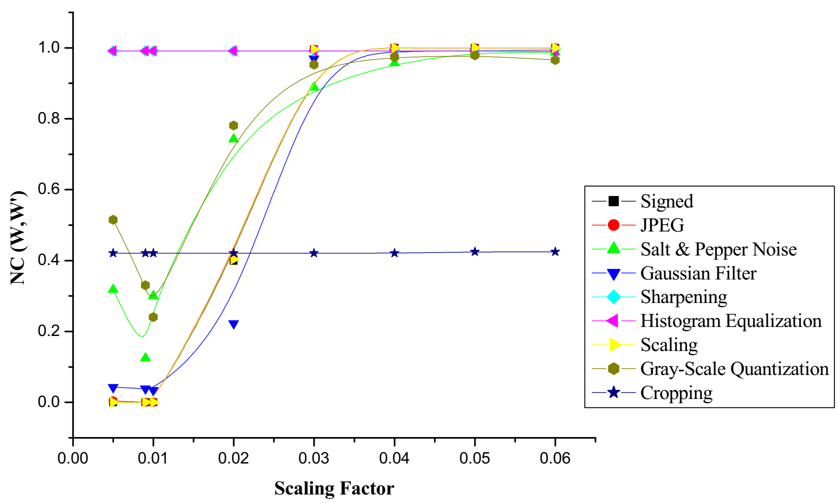

Fig. 1. Effect of scaling factor (δ) on $NC(W, W')$ values.

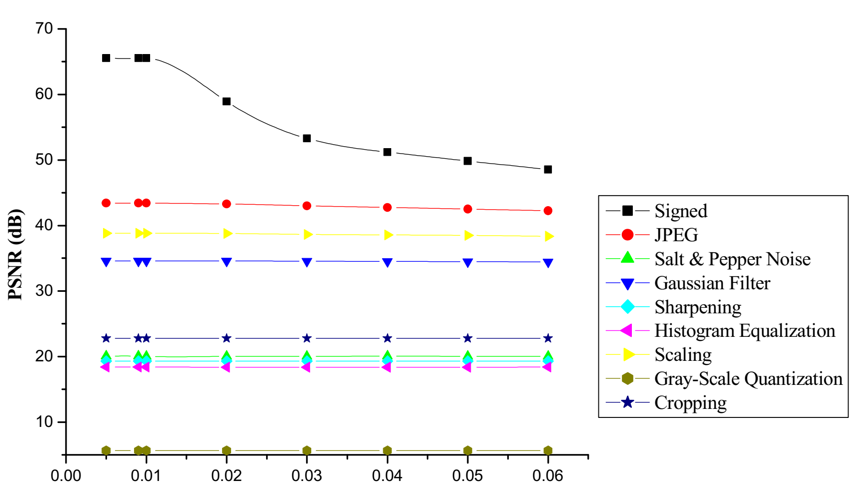

Fig. 2. Effect of scaling factor (δ) on PSNR.

mark embedding should take both PSNR and $NC(W, W')$ into account. This objective function is subsequently used to optimize the value of MSFs (δ) to obtain the best results.

5. Firefly based watermarking algorithm to optimize scaling factors

In this paper, we propose a DWT–SVD based watermarking scheme which makes use of MSF (δ) by using a recently developed optimization tool known as FA. This FA based DWT–SVD watermarking scheme makes use of the embedding and extraction algorithm presented in Listing 2 and 3 respectively. This watermarking scheme is given in Listing 4.

5.1.1. Listing 4: firefly algorithm based DWT–SVD watermarking scheme

Step1. Initialize n fireflies randomly, where each firefly is a row vector of size $m \times m$ (equal to the size of watermark).

Step2. For each firefly i of the firefly population do as follows:

i. Execute the watermark embedding algorithm given in Listing 2, Section 3.1 by using the Eqn. (19) instead of Eq. (13)

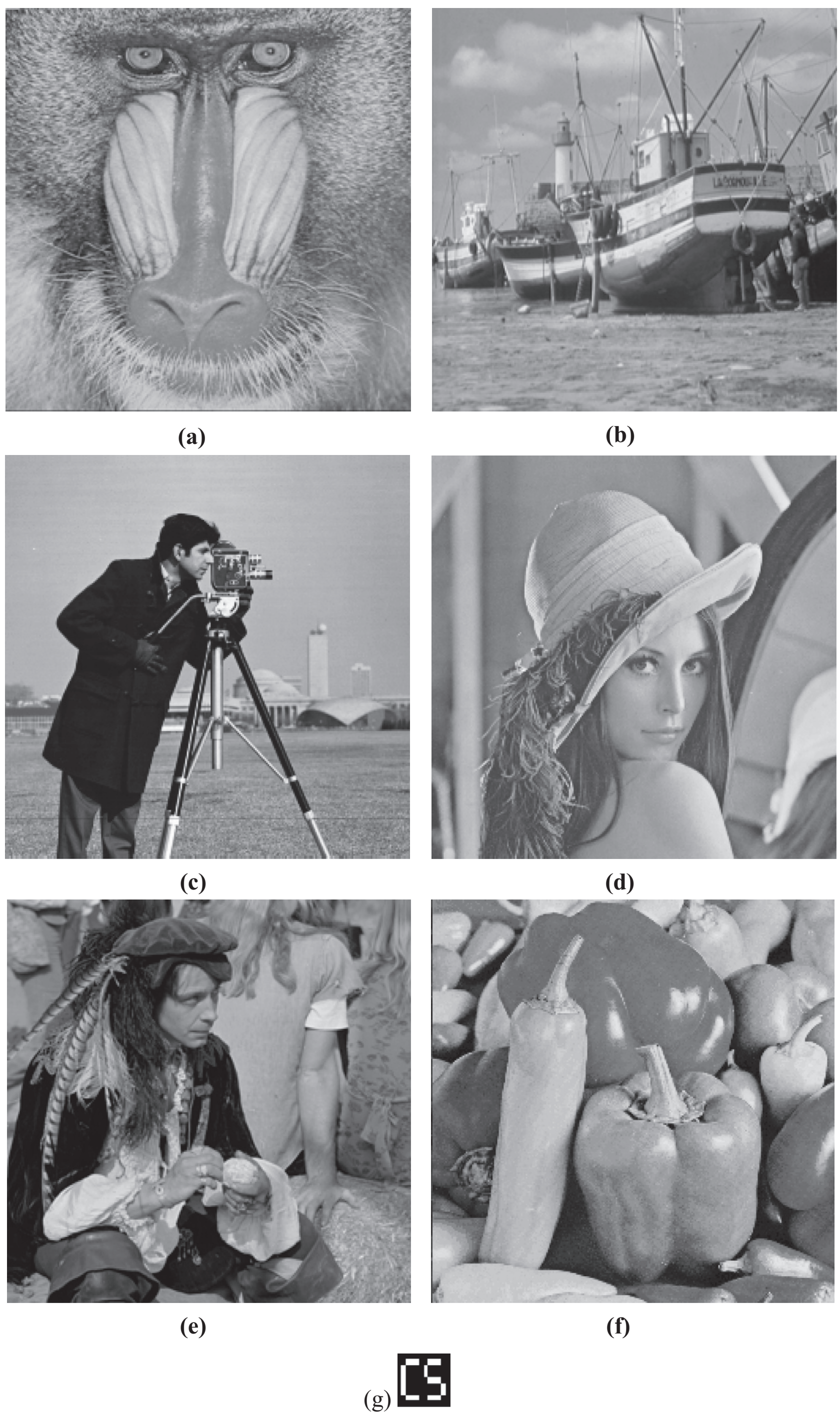

Fig. 3. (a–g). Original (a) baboon, (b) boat, (c) cameraman, (d) Lena, (e) man, (f) pepper and (g) watermark.

$$S' = S + \delta * S_w \tag{19}$$

where δ is the MSF obtained by FA.

ii. Apply T different image processing attacks on the signed image I' one by one. This generates T different attacked watermarked images for the signed image I'.
iii. Extract the watermarks form the attacked watermarked images using the algorithm given in Listing 3.
iv. Compute the PSNR between the original image I and signed image I' and $NC(W,W')$ values for attacked images.
v. Calculate the objective value of firefly (x) using objective function given by Eq. (20)

$$\text{objective} = \text{PSNR} + \phi * [NC(W,W') + \sum_{i=1}^{T} NC(W,W'_i)] \tag{20}$$

where $NC(W,W')$ is the normalized cross-correlation between the original watermark and extracted watermark from signed image, $NC(W,W'_i)$ is the normalized cross-correlation between the original watermark and extracted watermarks from each attacked signed image and ϕ is the weighting factor for NC values.

Step3. Move these n fireflies according to the procedure given in Listing 1.
Step4. Repeat Step2 and Step3 until the maximum number of generations (ML) is reached.

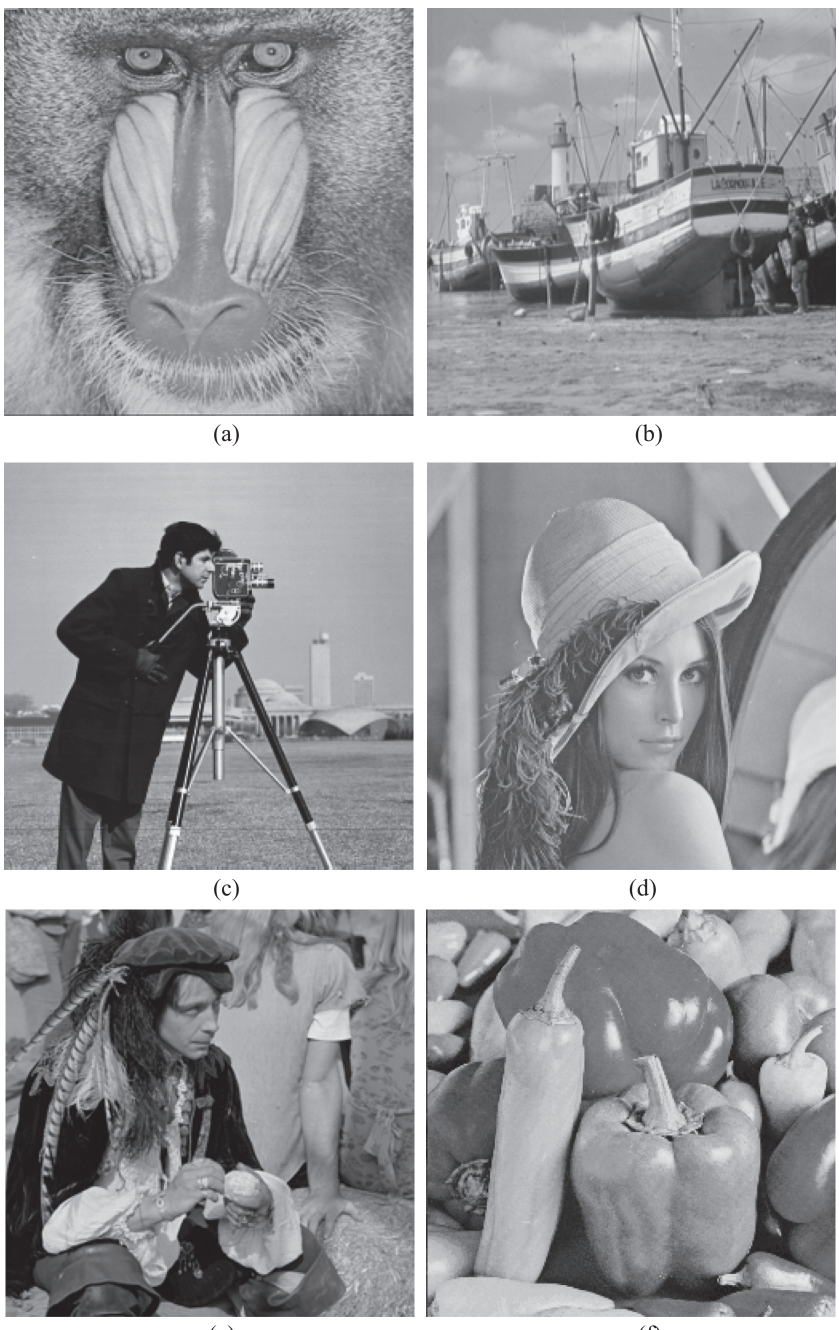

Fig. 4. (a–f). (a) Baboon watermarked image, (b) boat watermarked image, (c) cameraman watermarked image, (d) Lena watermarked image, (e) man watermarked image, and (f) pepper watermarked image.

In Eq. (20) above, the PSNR is much larger as compared to the associated NC values therefore; a weighting factor ϕ is used to balance out the influences caused by the two parameters (Shih & Wu, 2005; Shieh et al., 2004; Huang et al., 2010).

6. Experimental results and discussion

The performance of the proposed algorithm is evaluated on six different 256×256 gray-scale host images namely baboon, boat, cameraman, LENA, man and pepper. A 32×32 binary image is used as a watermark. All our experiments were carried out by using $\beta_0 = 1$, $\alpha = 0.01$ and $\gamma = 1.0$ (Yang, 2008; Horng & Jiang, 2010). The total number of initial fireflies (n) is 10, ϕ is10 and the simulation is done for ML = 10 iterations. To compute the objective function, eight image processing operations are executed as attacks ($T = 8$). These attacks are described in Section1. Fig. 3 depicts the host images and the binary watermark. Fig. 4 depicts the signed images and Fig. 5 depicts their corresponding extracted watermarks.

As mentioned in Section 5, our objective function is a linear combination of PSNR and $NC(W,W')$ obtained from signed and attacked images. This objective function is computed by taking into account eight different image processing operations. The FA uses this objective function to optimize the MSF used for watermark embedding. The optimized MSF is expected to enhance the robustness as compared to using a SSF. Table 1 compiles our results as well as those of several other researchers (Xianghong et al., 2004; Ishtiaq et al., 2010; Loukhaoukha et al., 2011) based on SSF as well as MSF for signed images only. We analyze and compare these results on the basis of optimized MSF using FA.

A careful observation of Table 1 indicates the following points:

(a) The average PSNR ranges between 50 and 55 (dB) for the six images, which indicates good visual quality of signed images.

(b) It is clear that our results for PSNR outperform those of other methods using SSF (Xianghong et al., 2004) and MSF (Loukhaoukha et al., 2011) for all host images except Baboon and Boat. On the other hand, our scheme outperforms the results of Ishtiaq et al. (2010) for Baboon, Boat and Lena images for PSNR. Note that Ishtiaq et al. (2010) only uses DCT as the transform technique to implement PSO based watermarking. Both Loukhaoukha et al. (2011) and us have used hybrid transforms to implement respective watermarking schemes. In Table 1, 'NA' indicates non-availability of reported values by Ishtiaq et al. (2010). In addition to this, our results of $NC(W,W')$ are same as those reported for all six host images.

(c) In our experiment, the PSNR computed using MSF is better than that computed using SSF for three host images – cameraman, Lena and pepper. For remaining three images the PSNR is slightly better for SSF.

(d) In our experiment, the computed $NC(W,W')$ values are universally better for all host images using MSF. This indicates that the robustness is clearly better in the case of the proposed algorithm for all six host images.

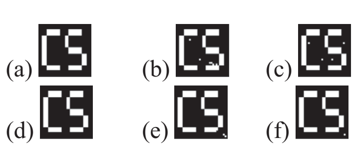

Fig. 5. (a–f). (a) Extracted watermark from Fig. 4(a), (b) extracted watermark from Fig. 4(b), (c) extracted watermark from Fig. 4(c), (d) extracted watermark from Fig. 4(d), (e) extracted watermark from Fig. 4(e) and (f) extracted watermark from Fig. 3(f).

(e) A close comparison between SSF based results obtained by us with the SSF results presented by Loukhaoukha et al. (2011) clearly reveal that our results are better as we have applied DWT–SVD combination while Loukhaoukha et al. (2011) have used LWT–SVD in their work.

We select eight different image processing operations as attacks to evaluate the robustness of the proposed scheme. These are: JPEG compression ($Q = 95$), salt and pepper noise (5%), Gaussian filtering (filter aperture = 3×3), sharpening (aperture = 0.2), histogram equalization (with 64 discrete gray levels), scaling ($256 \rightarrow 512 \rightarrow 256$), gray-scale quantization (1-bit) and cropping by dividing the image into 9 equal blocks, replacing the central block with zeros. Table 2 compiles the $NC(W,W')$ values for eight different image processing attacks in a similar manner as that of Table 1.

It is clear from Table 2 that the proposed watermark embedding and extraction scheme outperforms all other schemes for all image processing operations except sharpening and cropping. We attribute better results for robustness obtained by us to better optimization of MSF (δ) using FA. The FA makes use of the objective function which is a linear combination of PSNR of signed image and $NC(W,W')$ for both signed and attacked images computed for eight different attacks. This is explicitly correlated with the behavior of plots depicted in Figs. 1 and 2. It is clear that for most attacks, the $NC(W,W')$ values vary between the range $\delta = 0.005–0.06$. There by achieving high robustness. At the same time, the proposed algorithm maintains good perceptible quality of signed and attacked images as well correlated with Fig. 2. We therefore, conclude that the twin requirements of visual quality and robustness are successfully achieved in our scheme as a result of taking into account the MSFs optimized by the FA.

Table 1
PSNR and $NC(W,W')$ value between the host image and signed image of the proposed work and other's work.

Image	Algorithm	PSNR (dB)	$NC(W,W')$
Baboon	Proposed method (SSF)	53.0487	1.000
	Proposed method (MSF)	**50.76746**	**1.000**
	Loukhaoukha et al. (2011)	52.379	1.000
	Ishtiaq et al. (2010)	44.9624	NA
	Xianghong et al. (2004)	49.075	0.999
Boat	Proposed method (SSF)	54.0508	0.991
	Proposed method (MSF)	**51.49438**	**1.000**
	Loukhaoukha et al. (2011)	54.810	1.000
	Ishtiaq et al. (2010)	50.1586	NA
	Xianghong et al. (2004)	49.075	1.000
Cameraman	Proposed method (SSF)	53.5651	0.995
	Proposed method (MSF)	**53.65498**	**1.000**
	Loukhaoukha et al. (2011)	48.902	1.000
	Ishtiaq et al. (2010)	NA	NA
	Xianghong et al. (2004)	49.075	1.000
Lena	Proposed method (SSF)	53.3062	0.995
	Proposed method (MSF)	**55.7296**	**1.000**
	Loukhaoukha et al. (2011)	47.718	1.000
	Ishtiaq et al. (2010)	48.105	NA
	Xianghong et al. (2004)	49.075	1.000
Man	Proposed method (SSF)	53.7479	1.000
	Proposed method (MSF)	**51.1733**	**1.000**
	Loukhaoukha et al. (2011)	50.181	1.000
	Ishtiaq et al. (2010)	NA	NA
	Xianghong et al. (2004)	49.075	1.000
Peppers	Proposed method (SSF)	52.09	1.000
	Proposed method (MSF)	**52.15925**	**1.000**
	Loukhaoukha et al. (2011)	48.097	1.000
	Ishtiaq et al. (2010)	NA	NA
	Xianghong et al. (2004)	49.075	0.999

Table 2
Comparison of $NC(W,W')$ values of the proposed algorithm with other similar works for different image processing attacks.

	Algorithm	JPEG 5%	Noise	Gaussian filter 3 × 3	Sharpening	Histogram equalization	Scaling	Gray-scale quantization 1-bit	Cropping 1/8
Baboon	Proposed method(SSF)	1.000	0.970	0.920	0.991	0.794	1.000	0.712	0.572
	Proposed method (MSF)	1.000	0.991	0.993	0.991	0.999	1.000	0.996	0.699
	Loukhaoukha et al. (2011)	0.986	0.975	0.985	0.985	0.995	1.000	0.995	0.987
	Xianghong et al. (2004)	0.633	0.694	0.858	0.713	0.440	0.986	0.570	0.983
Boat	Proposed method (SSF)	0.987	0.527	0.480	0.995	0.811	0.995	0.763	0.394
	Proposed method (MSF)	1.000	0.998	0.984	0.991	0.997	1.000	0.99	0.756
	Loukhaoukha et al. (2011)	0.994	0.987	0.975	0.996	0.994	1.000	0.995	0.981
	Xianghong et al. (2004)	0.575	0.555	0.843	0.723	0.486	0.992	0.814	0.983
Cameraman	Proposed method (SSF)	0.995	0.609	0.957	0.849	1.000	0.995	0.978	0.433
	Proposed method (MSF)	1.000	0.973	0.981	0.905	1.000	1.000	0.989	0.533
	Loukhaoukha et al. (2011)	0.963	0.968	0.970	0.982	0.981	1.000	0.978	0.941
	Xianghong et al. (2004)	0.621	0.495	0.847	0.580	0.621	0.993	0.750	0.983
Lena	Proposed method (SSF)	0.995	0.700	0.970	0.991	0.991	0.997	0.953	0.421
	Proposed method (MSF)	1.000	0.979	0.991	0.9957	0.994	1.000	0.984	0.490
	Loukhaoukha et al. (2011)	0.976	0.963	0.993	0.986	0.991	1.000	0.983	0.946
	Xianghong et al. (2004)	0.640	0.616	0.866	0.667	0.587	0.994	0.625	0.983
Man	Proposed method (SSF)	1.000	0.609	0.884	0.729	0.943	1.000	0.931	0.721
	Proposed method (MSF)	1.000	0.989	0.9585	0.9798	0.987	1.000	0.988	0.724
	Loukhaoukha et al. (2011)	0.973	0.977	0.948	0.977	0.988	1.000	0.986	0.973
	Xianghong et al. (2004)	0.641	0.738	0.876	0.692	0.828	0.993	0.456	0.983
Pepper	Proposed method (SSF)	1.000	0.609	0.965	0.849	0.995	1.000	0.961	0.188
	Proposed method (MSF)	1.000	0.988	0.995	0.954	1.000	1.000	0.991	0.758
	Loukhaoukha et al. (2011)	0.975	0.968	0.986	0.991	0.994	1.000	0.980	0.964
	Xianghong et al. (2004)	0.610	0.713	0.819	0.699	0.749	0.997	0.534	0.983

7. Conclusion

Presently, the problem of image watermarking has acquired the status of optimizing twin parameters – visibility of signed and attacked images and robustness of the watermark embedding scheme. The issue of using embedding strength based on single scaling factor (SSF) or multiple scaling factor (MSF) is also found to converge with this objective. For quite some time, evolutionary algorithms of variable nature are being employed to achieve this outcome.

This paper proposes an optimized watermark embedding and extraction scheme based on combining DWT and SVD transforms. The singular values of LL3 sub-band coefficients of the host image are modified using singular values of a binary watermark image using MSFs. The MSFs are optimized using a newly proposed FA having an objective function which is a linear combination of imperceptibility and robustness. The major contribution of the proposed scheme is the application of FA for identifying optimal multiple scaling factors. Experimental results show that the proposed scheme yields high PSNR values, which indicate that the visual quality of the signed and attacked images is good and the embedding scheme show high robustness against selected image processing operations. For eight different image processing attacks used in this work, the computed $NC(W,W')$ values are found to be sufficiently large. The advantage of the proposed technique is that it adaptively selects the optimal multiple scaling factors, thereby producing best results as compared to other similar works. The twin requirements of imperceptibility and robustness are successfully achieved in our scheme as a result of taking into account the MSFs optimized by the FA. We also compare the performance of our scheme with a single scaling watermarking scheme (Xianghong et al., 2004) and multiple scaling watermarking scheme (Ishtiaq et al., 2010; Loukhaoukha et al., 2011) and show that the proposed scheme outperforms both schemes under various image processing operations except sharpening and cropping attacks. The proposed scheme shows a definite improvement over other similar reported swarm intelligence cum meta-heuristic methods.

As discussed in Section 6, the novel evolutionary algorithm – FA yields comparatively better results for different application. Although, we propose use of this algorithm for image watermarking, yet this work is not extended to video of both types – compressed and uncompressed. However, to achieve this, real time constraints have also to be taken into consideration. For this purpose, the time complexity computation for embedding and extraction will have to be examined and carried out. We are sure that FA can be potential technique to achieve this objective.

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