Optimized DWT SVD Based Image Watermarking Scheme Using Particle Swarm Optimization

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Abstract. The robust watermarking techniques have gained popularity over last decade as more and more digital contents are being shared over Internet. This increase in data transmission also poses greater risk of various attacks which hamper data authenticity, integrity and quality. Therefore, efficient mechanisms are required that can handle robust transmission of digital data while honoring the Digital Right Management (DRM) protection measures of copyrighted content. In this paper, we explore an optimized Particle Swarm Optimization (PSO) based watermarking scheme on digital images in the hybrid Discrete wavelet transform (DWT) and Singular value decomposition (SVD) transform. The watermark is embedded in the host images by using both single scaling and multiple scaling factors for optimizing the visual quality of the signed images viz-a-viz robustness. Eight gray-scale and six colored images are used to carry out the experiments. Comparison of the proposed watermarking scheme with other techniques ascertain the proposed scheme outperforms others and it also fulfills all requisite conditions to be a robust and optimized watermarking scheme.

Keywords: Image watermarking · Transform domain · Discrete wavelet transform · Singular value decomposition

1 Introduction

In recent years, there is a vast increase in the amount of digital data communicated across the network. This has raised the security concerns related to authenticity and ownership of the data across Internet. Watermarking has emerged out as one of the solutions to above problems. Digital watermarking is a process for copyright protection and owner identification and verification in which a copyright data is embedded into the cover image as watermark in an invisible or visible manner that can be extracted later without much degradation of the cover signed image and the watermark [1, 2].

In this regard, visual quality of the signed images and robustness of the embedding scheme are two important parameters to quantify the performance of the watermarking scheme. Since both parameters are inversely related to each other, in lieu of this, watermarking can be visualized as an optimization problem. Cox et al. [1] proposed
three groups to classify most commonly used watermarking schemes: Robust, Fragile, and Semi-fragile. Robust watermarking schemes are used for copyright protection and are resilient against compression, geometric and counterfeit attacks [3]. The fragile and semi-fragile techniques are used when the focus is on image integrity and authenticity. The watermark is embedded in fragile framework in such manner that any attempt to modify signed image will result in complete distortion of the watermark. The semi-fragile watermarks are developed to harness benefits of both robust and fragile framework. When the embedding process is carried out in the spatial domain of image, it leads to fragile watermarking. Such kind of watermarking results in directly changing the bits of the host image, thus, ease the implementation but compromises on the robustness of scheme against various attacks [3, 4]. On the other hand, watermarking in the transform domain results in embedding the watermark in the frequency domain coefficients of host image and has been found to be a more robust watermarking scheme. Out of various frequency domain techniques like Discrete Fourier Transform (DFT) [5, 6], Discrete Cosine Transform (DCT) [7, 8, 26] and Discrete Wavelet Transform (DWT) [9, 10, 25, 33], DWT has been found to achieve an imperceptible watermarking along with high robustness [1]. Xianghong et al. [29] proposed DWT in conjunction with vector transform as watermark embedding scheme. They have used single scaling factor for embedding the watermark in host image. These techniques have further been used in collaboration with other techniques like Singular value decomposition (SVD) [2, 11, 23, 27] for better watermarking efficiency.

The secure transmission of digital images has greatly evolved from the initial proposed algorithms like DFT, DCT to more sophisticated soft computing techniques like artificial neural networks, fuzzy logic systems, support vector machines along with HVS model [12–16, 24]. Mishra et al. [17] have proposed watermarking scheme based on characteristics of human visual model. They have exploited three HVS features and fed them into FIS. They have also integrated a single layer feed-forward neural network known as extreme machine learning to generate the watermark. They claimed that their scheme is capable to implement real time watermarking applications.

The last decade has seen numerous applications having origin in nature inspired techniques to efficiently solve optimization problems. Hybridization of different meta-heuristic techniques – Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO) and nature inspired algorithms like Spider monkey, Cuckoo search and Artificial Bee Colony optimization along with transform domain techniques have also been explored and reported. Lai et al. [18] presented tiny genetic algorithm in conjunction with the SVD transform domain. In their work, they used tiny-GA to compute the values of embedding scaling factors to optimize the parameters of watermarking algorithm. Agarwal et al. [19] proposed their watermarking scheme using cuckoo search algorithm. In their scheme, they have embedded the watermark in different coefficients of the host image using multiple scaling factors which they have optimized using CSA. Loukhaoukha et al. [30] have used multi-objective ant colony optimization technique in LWT-SVD domain while Ishfaq et al. [32] have proposed the Particle Swarm Optimization technique to find the optimal values for multiple scaling factors. Mishra et al. [20] have presented their widely cited hybrid watermarking scheme in DWT domain using famous Firefly Optimization for gray-scale images. They have decomposed LL3 sub-band coefficients into singular
values using SVD to embed the watermark. They have nicely analyzed the use of Multiple Scaling Factors (MSFs) for embedding the watermark in the images. The MSFs are generated through Firefly Algorithm by using an Objective Function (Obj) which is composed of the PSNR and all image processing operations they used to attack the signed images. Their results were superior to all other such schemes falling in the same category. Abdelhakim [31] have suggested a combination of DCT with Artificial Bee Colony for the optimization of watermarking scheme. They claimed that their proposed technique minimized the error between optimal and predicted solutions for watermark embedding. Kuppusamy et al. [21] have proposed a PSO based watermarking algorithm in daubechies4 transform domain. They employed various attacks over the signed images and claimed good results of their scheme using IQIM. Loukhaoukha et al. [22] have hybridized multi-objective particle swarm optimization technique with SVD in wavelet domain for watermarking. They showed significant improvement in their results with the use of MSFs for watermark embedding.

Image watermarking is performed by using embedding strength ($\theta$) which can be either single valued i.e. Single Scaling Factor (SSF) or there can be multiple values of the embedding strength i.e., Multiple Scaling Factors (MSFs). The SSF takes constant numerical value for every coefficient of the host image for watermarking purpose. Thus, it does not consider variations in the physical parameters like contrast and intensity of the host image. However, it has been seen that different regions of image vary in their structural and physical properties which disturbs the visibility of the signed image especially in the smoother regions [1, 4, 14]. Thus, MSF plays an important role in optimizing the results for an efficient watermarking scheme. The MSF considers different values for different coefficients of host image and thus, embedding the watermark with lesser strength in smoother areas as compared to the high intensity areas of the host image.

In this paper, we propose an optimized hybrid watermarking scheme using DWT-SVD based on PSO technique. We have carried out the watermark embedding using both the SSF and MSF in gray-scale and colored images for the sake of comparison. Our proposed scheme further examines the robustness parameter by employing various image process attacks which are also used in the Objective Function. This Objective Function happens to be a linear function of PSNR value of signed image and sum of Normalized Correlation (NC) values for attacked images. The research paper is organized as follows:

It presents the brief introduction of PSO along with its necessary mathematical inputs in Sect. 2. The Sect. 3 comprises of the proposed embedding and extraction schemes. Section 4 contains our experimental results and their analysis on the basis of its comparison with other hybrid schemes. Section 5 concludes the whole work.

2 Particle Swarm Optimization

PSO is a population-based global optimization technique modelled by Kennedy and Eberhart [28]. PSO is a meta-heuristic technique that is based on co-operative and social characteristics of evolution like flocking of birds, insects swarming as compared to other evolutionary strategies like genetic algorithms that use competitive aspects like
survival of the fittest. PSO involves creating a diffuse population (known as swarm) of individuals (termed as particles) that tend to move in the search space and clustering in areas where local minima are located. In each iteration, particles learn from their surroundings and on that basis, update their positions and velocities which are based on the combination of best positions found by that particle (personal best, pbest) and also, the best position value achieved by entire swarm (global best, gbest).

Listing 1. Pseudo-Code of PSO

**Input:** a) An objective function $\text{obj}(x)$, $x = [x_1, x_2, ..., x_m]^T$

b) A random population (swarms) of particles $s_i$, $i = 1, 2, ..., n$

c) Inertial weight: $w = 1$, acceleration constants: $\varrho_1 = 1, \varrho_2 = 2$

d) Uniformly distributed random vectors: $r_1, r_2 = [0,1]$, maximum number of iterations: $\text{max}Itr$

**Begin**

for each $s_i$

generate a random position vector $P_i = U(\text{low}, \text{high})$

if $\text{obj}(\text{pbest}_i) > \text{obj}(\text{gbest})$

$\text{gbest} \mapsto \text{pbest}_i$

end if

generate a random velocity vector $V_i = U(-|\text{high} - \text{low}|, |\text{high} - \text{low}|)$

end for

while $(t < \text{max}Itr)$ or (StopCriterion)

for each $s_i$

Compute its velocity

$V_i^{(t+1)} = wV_i^{(t)} + \varrho_1 r_1(\text{pbest}_i - P_i^{(t)}) + \varrho_2 r_2(\text{gbest} - P_i^{(t)})$

Update its position

$P_i^{(t+1)} = P_i^{(t)} + V_i^{(t+1)}$

if $\text{obj}(P_i) > \text{obj}(\text{pbest}_i)$

$\text{pbest}_i \mapsto P_i$

end if

if $\text{obj}(\text{pbest}_i) > \text{obj}(\text{gbest})$

$\text{gbest} \mapsto \text{pbest}_i$

end if

end for

end while

**End**

With each iteration, particles tend to move closer and converge towards a single point. The output generated by PSO largely depends on the values of parameters used like inertial weight $w$, maximum number of iterations used $\text{max}Itr$ and the acceleration
constants $\varnothing_1$ and $\varnothing_2$. As the process terminates, the best solution is denoted by gbest which provides the optimal solution.

3 Proposed Method

In the proposed scheme, host image ($I$) of $512 \times 512$ and binary watermark ($W$) of size $32 \times 32$ are used for embedding and extraction process. The embedding is carried out in the transform domain by partitioning the host image into sub-bands using 4-level DWT and decomposing the coefficients using SVD as explained in Sect. 3.1. The extraction process is executed as the reverse procedure of embedding and is explained in Sect. 3.2 in detail.

3.1 Watermark Embedding

In the embedding process, the bits of the host image are altered according to the values of the coefficients of watermark to be inserted. Figure 1 represents the procedure through block diagram. A good embedding is determined by the visual quality of the signed images. The metric PSNR measures peak signal to noise ratio and determines the quality of embedding. Higher values of PSNR reflects higher visual quality of the signed images. It is given by the equation:

$$PSNR = 10\log_{10}\left(\frac{I_{max}^2}{MSE}\right)$$  \hspace{1cm} (1)

where, $I_{max}$ defines the maximum pixel intensity for image $I$ and MSE denotes mean square error.

![Fig. 1. Block diagram of watermark embedding](image)

Listing 2. Embedding Process

- Decompose the host image using 4-level DWT HAAR wavelet transform into four sub-bands: LL4, LH4, HH4, HL4.
- For good robustness, use LL4 sub-band for watermark embedding.
- For unique feature extraction, perform SVD on LL4 sub band of host image and obtain S using equation:

\[
[USV] = SVD(LL4)
\]  

(2)

- Apply SVD on the watermark (W) used to achieve singular value matrix \( (S_w) \) using following equation:

\[
[U_wS_wV_w] = SVD(W)
\]  

(3)

- Embed the watermark coefficients \( (S_w) \) into the obtained coefficients of host image \( (S) \) using equation:

\[
S' = S + \alpha \cdot S_w
\]

where, \( \alpha \) represents the embedding scaling factor that needs to be optimized.
- Obtain modified coefficients using equation given below:

\[
LLA' = [US'VT]
\]

(5)

- Perform IDWT on the above modified coefficients resulting into signed image.

3.2 Watermark Extraction

This process recovers the extracted watermark from the signed image. The process is represented through the block diagram in Fig. 2. A good watermark extraction scheme should be robust to the image processing attacks. To measure the robustness of the scheme, NC \((W, W')\) (normalized cross-correlation) coefficient is computed for the original watermark \( (W) \) from host image and the recovered watermark \( (W') \) from the signed image using the equation:

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

(6)

The values closer to 1 indicate good recovery of the watermark from the signed image and hence, high robustness of the watermarking scheme.

Listing 3: Extraction Process

- For recovery, apply 4- level DWT on the host image and signed image.
- Retrieve LL4 and \( LLA' \) sub band coefficients from both the images respectively.
Apply SVD on above calculated coefficients and obtain corresponding singular values $S$ and $S'$ values using the following equations:

$$[USV] = SVD(LL4)$$

$$[U'S'V'] = SVD(LL4')$$

Extract the singular values of the watermark ($S'_w$) through formula given by equation:

$$S'_w = (S' - S) / \propto$$

Recover the watermark ($W'$) using equation given below:

$$W' = [U'_wS'_wV'^T]$$

### 3.3 PSO Based Watermarking Algorithm for Scaling Factor Optimization

In this scheme, the watermark coefficients are embedded in the host image using the multiple scaling factor ($\propto$). This embedding is performed in the transform domain using discrete wavelet transform and singular value decomposition. The MSF $'\propto'$ is optimized using PSO algorithm.

**Listing 4: PSO based watermarking scheme**

- Create an initial population of $n$ swarms randomly, where each particle has position vector of size $m \times m$. This corresponds to the size of binary watermark used.
For each particle of swarm $s_i$:

i) Perform watermark embedding in the host image using algorithm in Listing 2. MSF 's used in Eq. (4) is optimized by PSO algorithm given in Listing 1.

ii) Generate $T$ different attacked signed images by executing $T$ image-processing attacks on obtained signed image $I'$.

iii) Perform watermark extraction on all attacked signed images using the watermark extraction algorithm given in Listing 3.

iv) Calculate the visual quality of signed image $I'$ using PSNR by Eq. (1) and robustness of the watermarking scheme using $\text{NC}(W, W')$ values for the attacked signed images using Eq. (6).

v) Finally, compute the value of objective function of the swarm using the function given by following equation:

$$\text{Obj} = \text{PSNR} + \delta \left[ \text{NC}(W, W') + \sum_{i=1}^{n} \text{NC}(W, W_i') \right]$$

where, $\delta$ is the weighting factor for $\text{NC}(W, W')$ values. This factor is required to create balance in the equation since PSNR value largely outweighs $\text{NC}(W, W')$ values.

- Update each swarm’s global position with the best value according to the objective function value achieved above.
- Optimize the swarms using the algorithm given in Listing 1.
- Repeat the above steps till termination criteria are met.

4 Experimental Results

Experiments are performed on eight $512 \times 512$ gray scale host images: Baboon, Boat, Lena, Cameraman, Parrots, Tiger, Jumbo and Cosmological Cabbage. Embedding is done using $32 \times 32$ binary image as watermark. The PSO parameters: $w = 1$, $\varnothing_1 = 1$, $\varnothing_2 = 2$, maxItr = 10 and swarm size ($n$) = 20 are set. MATLAB 2018 is used to perform the experiments on MacBook Air 1.6 GHz Intel Core i5 on macOS Catalina version 10.15.4.

4.1 Effect of SSF and MSF Over Visual Quality of Signed Images

The use of SSF results in embedding the watermark with same strength in the entire host image. Table 1 compiles the PSNR and $\text{NC}(W, W')$ values of the four gray scale signed images used in the present work. These four test images are used by us as other researchers have used the same test images and this becomes a mandatory criterion to present a comparative assessment of various other schemes vis-à-vis the proposed one. Table 2 compiles the PSNR and $\text{NC}(W, W')$ values of four additional gray scale signed images used in our work without any such comparison.
A close observation of the data compiled in Table 1 reveals that embedding the watermark using the MSF strategy gives better results as compared to the SSF strategy in proposed scheme. We also compare our MSF and SSF results with the same of other schemes belonging to the similar category. Clearly, our results outperform the results presented by other state of art works. This is found true both the PSNR and NC $\langle W, W' \rangle$ parameter of the signed images. Table 2 further compiles results of PSNR and

| Image   | Algorithm                            | PSNR (DB) | NC $\langle W, W' \rangle$ |
|---------|--------------------------------------|-----------|----------------------------|
| Baboon  | Suggested scheme (SSF)               | 56.8489   | 1.000                      |
|         | Suggested scheme (MSF)               | 60.9734   | 1.000                      |
|         | Loukhaoukha et al. (2011) (MSF)      | 52.379    | 1.000                      |
|         | Ishtiaq et al. (2010) (MSF)          | 44.9624   | NA                        |
|         | Xianghong et al. (2004) (SSF)        | 49.075    | 0.999                      |
| Boat    | Suggested scheme (SSF)               | 52.5321   | 1.000                      |
|         | Suggested scheme (MSF)               | 56.6840   | 1.000                      |
|         | Loukhaoukha et al. (2011) (MSF)      | 54.810    | 1.000                      |
|         | Ishtiaq et al. (2010) (MSF)          | 50.1586   | NA                        |
|         | Xianghong et al. (2004) (SSF)        | 49.075    | 1.000                      |
| Lena    | Suggested scheme (SSF)               | 55.8539   | 1.000                      |
|         | Suggested scheme (MSF)               | 59.2610   | 1.000                      |
|         | Loukhaoukha et al. (2011) (MSF)      | 47.718    | 1.000                      |
|         | Ishtiaq et al. (2010) (MSF)          | 48.105    | NA                        |
|         | Xianghong et al. (2004) (SSF)        | 49.075    | 1.000                      |
| Cameraman | Suggested scheme (SSF)             | 54.4182   | 1.000                      |
|         | Suggested scheme (MSF)               | 57.8539   | 1.000                      |
|         | Loukhaoukha et al. (2011) (MSF)      | 48.902    | 1.000                      |
|         | Ishtiaq et al. (2010) (MSF)          | NA        | NA                        |
|         | Xianghong et al. (2004) (SSF)        | 49.075    | 1.000                      |
NC \((W, W')\) parameters for four more gray scale images used in our work both for SSF and MSF strategies. In this case also, the MSF strategy outperforms the SSF strategy. The PSNR values for all four signed images are better placed for MSF while the NC \((W, W')\) parameter is already found to be maximum \((NC (W, W') = 1.000)\) both for SSF and MSF strategies. This again proves that MSF is better in comparison to SSF for all eight gray-scale images used in the proposed scheme.

### 4.2 Effect of SSF and MSF Over the Robustness of Watermarking Scheme

In the next part of this work, the next two tables compile the results for robustness studies carried out over these eight signed images by considering both SSF and MSF strategies. This is carried out to make an assessment of these embedding strategies over the robustness of the embedded watermark. Due to paucity of space and formatting issues, these results are divided into two tables – Table 3 and 4 respectively. The six image processing attacks being used in this work are - JPEG compression (with 10\%, 20\% and 30\% compression ratios or QF = 0.9, 0.8 and 0.7 respectively), Noise addition (Salt & Pepper noise and Gaussian noise 5\% each), Filtering (Gaussian filter and Median filter with Aperture size = 3), Cropping ((i) Crop the center of signed image with window size = 64 \times 64 and replace it with the same window of the host image and (ii) Crop the corner of signed image with window size = 64 \times 64 and replace it with the same window of the host image), Histogram Equalization, Scaling (reducing the signed image to half and then resizing it back to original size).

| Image               | PSNR (SSF scheme) (dB) | PSNR (MSF scheme) (dB) | NC \((W, W')\) (SSF scheme) | NC \((W, W')\) (MSF scheme) |
|---------------------|------------------------|------------------------|-----------------------------|-----------------------------|
| Parrots             | 58.3182                | 61.3738                | 1.000                       | 1.000                       |
| Tiger               | 57.2842                | 60.4191                | 1.000                       | 1.000                       |
| Jumbo               | 54.5351                | 55.3924                | 1.000                       | 1.000                       |
| CosmologicalCabbage | 52.6182                | 54.0521                | 1.000                       | 1.000                       |
A close observation of Table 3 and Table 4 clearly indicates that the NC \((W, W')\) parameter values using MSF strategy for various image processing attacks are better as compared to SSF strategy. A high numerical value of the NC \((W, W')\) parameter indicates that the watermark recovery out of the signed images is quite good which indicates a high robustness of the proposed scheme. Therefore, it can be deduced that our DWT-SVD hybrid transform based PSO watermarking scheme is suitable for optimizing the twin parameters of visual quality of signed grayscale images and the robustness of the watermark embedding scheme in the same. The use of the PSO based optimization of the Multiple Scaling Factors for embedding under DWT-SVD hybrid transform is primarily responsible for this outcome.

| Image / Attacks | Baboon  | Boat  | Lena  | Cameraman |
|-----------------|---------|-------|-------|-----------|
|                 | SSF | MSF | SSF | MSF | SSF | MSF | SSF | MSF |
| JPEG (Q = 0.9)  | 0.9808 | 0.9841 | 0.9654 | 0.9759 | 0.9751 | 0.9818 | 0.9711 | 0.9897 |
| JPEG (Q = 0.8)  | 0.9728 | 0.9795 | 0.9527 | 0.9727 | 0.9742 | 0.9769 | 0.9604 | 0.9778 |
| JPEG (Q = 0.7)  | 0.9687 | 0.9724 | 0.9421 | 0.9614 | 0.9648 | 0.9702 | 0.9508 | 0.9622 |
| Salt & Pepper Noise (5%) | 0.9357 | 0.9672 | 0.8911 | 0.9238 | 0.9345 | 0.9601 | 0.9094 | 0.9274 |
| Gaussian Noise (5%) | 0.9489 | 0.9756 | 0.9032 | 0.9304 | 0.9387 | 0.9711 | 0.9105 | 0.9408 |
| Gaussian Filtering (3x3) | 0.9282 | 0.9576 | 0.9049 | 0.9304 | 0.9133 | 0.9416 | 0.9023 | 0.9404 |
| Median Filtering (3x3) | 0.9013 | 0.9453 | 0.8849 | 0.9131 | 0.8917 | 0.9379 | 0.8911 | 0.9299 |
| Cropping (crop 64 x 64 center and replace with host image) | 0.9557 | 0.9786 | 0.9297 | 0.9334 | 0.951 | 0.9617 | 0.9445 | 0.9531 |
| Cropping (crop 64 x 64 corner and replace with host image) | 0.9576 | 0.9733 | 0.9305 | 0.9417 | 0.9534 | 0.9687 | 0.947 | 0.9529 |
| Histogram Equalization | 0.9012 | 0.9107 | 0.8621 | 0.8859 | 0.8902 | 0.9074 | 0.8702 | 0.8913 |
| Scaling (5 1 2 > 2 5 6 > 5 1 2) | 0.9939 | 0.9977 | 0.9912 | 0.9928 | 0.9930 | 0.9956 | 0.991 | 0.9929 |
4.3 Study of PSO Optimization Over Colored Images

In the previous sections, we have established that for eight different gray scale images, the PSO based optimization scheme operating under DWT-SVD hybrid transform is found comparatively better for watermark embedding. To further test the effectiveness of our proposed scheme, we extend our research work to six compressed colored images depicted in Fig. 3, working with SSF and MSF strategies. These images are – Parrot, Baboon, Tiger, Lena, Jumbo and Cosmological Cabbage, all compressed as Jpeg compression standard. It is important to note that the use of compressed copyright material is one of the major important requirements of Digital Rights Management (DRM). Therefore, we use these images in Jpeg compressed domain for testing our watermarking scheme. We tabulate the obtained results for PSNR and NC $W_W^0/C_0/C_1$ in Table 5. Table 6 compiles the robustness studies data over the six colored images for SSF and MSF strategies. It is found that the results as obtained for the eight grayscale images reported in Sect. 4.2 and 4.3 above are repeated with MSF strategy out casting the SSF strategy in this case as well. Hence, it can be concluded that the PSO optimization has fairly performed well for colored images also. We conclude that the use of

Table 4. Compilation of NC $(W, W')$ values of gray scale signed images after various attacks (contd…)

| Image / Attacks | Parrots | Tiger | Jumbo | Cosmological Cabbage |
|----------------|---------|-------|-------|----------------------|
|                | SSF     | MSF   | SSF   | MSF                  |
| JPEG (Q = 0.9) | 0.9711  | 0.9801| 0.9586| 0.9797               |
| JPEG (Q = 0.8) | 0.9613  | 0.9797| 0.9492| 0.9667               |
| JPEG (Q = 0.7) | 0.9405  | 0.9523| 0.9073| 0.9586               |
| Salt & Pepper Noise (5%) | 0.9181 | 0.9279| 0.9216| 0.9405               |
| Gaussian Noise (5%) | 0.9077 | 0.9488| 0.9080| 0.9416               |
| Gaussian Filtering (3x3) | 0.9434 | 0.9579| 0.9181| 0.9345               |
| Median Filtering (3x3) | 0.9374 | 0.9591| 0.9096| 0.9273               |
| Cropping (crop 64 x 64 Center and replace with host image) | 0.9602 | 0.9721| 0.9591| 0.9656               |
| Cropping (crop 64 x 64 Corner and replace with host image) | 0.9522 | 0.9678| 0.9611| 0.9703               |
| Histogram Equalization | 0.9032 | 0.9102| 0.8993| 0.9015               |
| Scaling (5 1 2 > 2 5 6 > 5 1 2) | 0.9945 | 0.9981| 0.9942| 0.9977               |

Optimized DWT SVD Based Image Watermarking Scheme Using PSO
PSO optimization in DWT-SVD hybrid transform domain working with MSF embedding strategy is a good candidate for grayscale and compressed colored image watermarking. In the proposed scheme, all performance metrics have been verified and evaluated viz-a-viz., state of the art techniques and it has been found to outperform all of them.

**Fig. 3.** Color host images a) Parrots.jpg, b) Baboon.jpg, c) Tiger.jpg, d) Lena.jpg, e) Jumbo.jpg and f) CosmologicalCabbage.jpg (Color figure online)

**Table 5.** Compilation of PSNR and NC \((W, W')\) values of colored images under SSF and MSF strategies

| Image               | PSNR (SSF scheme) (dB) | PSNR (MSF scheme) (dB) | NC \((W, W')\) (SSF scheme) | NC \((W, W')\) (MSF scheme) |
|---------------------|------------------------|------------------------|-----------------------------|-----------------------------|
| Parrots             | 60.7181                | 64.8534                | 1.000                       | 1.000                       |
| Baboon              | 57.6204                | 63.6811                | 1.000                       | 1.000                       |
| Tiger               | 59.8275                | 62.7539                | 1.000                       | 1.000                       |
| Lena                | 60.0043                | 61.7653                | 1.000                       | 1.000                       |
| Jumbo               | 55.2116                | 57.8201                | 1.000                       | 1.000                       |
| Cosmological Cabbage| 55.8022                | 58.4118                | 1.000                       | 1.000                       |
We attribute better results obtained by us to the use of the hybrid objective function used to optimize the PSO technique. This objective function is a linear combination of the PSNR and the image processing attacks used in this work. This function has resulted in better optimization of the MSF for PSO based watermarking scheme.

5 Conclusion

The paper proposes an optimized PSO based watermarking scheme working in hybrid DWT-SVD transform domain. The PSO is used to determine the Multiple Scaling Factor (MSF) based embedding strength further used to embed the watermark in the image coefficients on the basis of its structural and physical properties. The experimentation is carried out over eight gray-scale and six colored images of the size \(512 \times 512\). The Objective function proposed by Mishra et al. which is a linear combination of the PSNR and six different image processing attacks is used to run the PSO algorithm. The optimized value of the MSFs so generated by the PSO is used to embed the watermark in the selected low frequency coefficients of the host images. The signed images so obtained are found to exhibit very high visual quality and the watermark embedding scheme is also found to be quite robust. The proposed watermarking scheme outperforms several other identical schemes with the observed results. It is found that the PSO based scheme carried out in hybrid DWT-SVD transform domain is

| Attacks/Image | Parrots | Baboon | Tiger | Lena | Jumbo | CosmologicalCabbage |
|---------------|---------|--------|-------|------|-------|---------------------|
| JPEG (Q = 0.9) | 0.9827  | 0.9915 | 0.9817 | 0.9908  | 0.9601  | 0.9841  | 0.9722  | 0.9869  | 0.9787  | 0.9821  | 0.9678  | 0.9765  |
| JPEG (Q = 0.8) | 0.9704  | 0.9844 | 0.9701 | 0.9802  | 0.9540  | 0.9713  | 0.9687  | 0.9742  | 0.9644  | 0.9706  | 0.9495  | 0.9634  |
| JPEG (Q = 0.7) | 0.9635  | 0.9736 | 0.9621 | 0.9742  | 0.9480  | 0.9673  | 0.9513  | 0.9681  | 0.9455  | 0.9703  | 0.9267  | 0.9356  |
| Salt & Pepper Noise (5%) | 0.9294  | 0.8493 | 0.9192 | 0.8472  | 0.9276  | 0.9511  | 0.9285  | 0.9605  | 0.9230  | 0.9521  | 0.9064  | 0.9330  |
| Gaussian Noise (5%) | 0.9335  | 0.9634 | 0.9264 | 0.9521  | 0.9474  | 0.9586  | 0.9384  | 0.9646  | 0.9453  | 0.9552  | 0.9195  | 0.9483  |
| Gaussian Filtering (3x3) | 0.9681  | 0.9829 | 0.9407 | 0.9643  | 0.9527  | 0.9814  | 0.9498  | 0.9785  | 0.9501  | 0.9792  | 0.9183  | 0.9571  |
| Median Filtering (3x3) | 0.9536  | 0.9663 | 0.9334 | 0.9575  | 0.9482  | 0.9710  | 0.9403  | 0.9648  | 0.9416  | 0.9702  | 0.9226  | 0.9536  |
| Cropping (crop 64 x 64 center and replace with host image) | 0.9723  | 0.9833 | 0.9636 | 0.9823  | 0.9661  | 0.9771  | 0.9628  | 0.9739  | 0.9523  | 0.9711  | 0.9498  | 0.9643  |
| Cropping (crop 64 x 64 corner and replace with host image) | 0.9766  | 0.9811 | 0.9688 | 0.9905  | 0.9584  | 0.9786  | 0.9604  | 0.9788  | 0.9566  | 0.9748  | 0.9512  | 0.9666  |
| Histogram Equalization | 0.9190  | 0.9279 | 0.9052 | 0.9197  | 0.9016  | 0.9172  | 0.9032  | 0.9204  | 0.8919  | 0.9110  | 0.8877  | 0.8990  |
| Scaling (5 1 2>2 5 6 5 2) | 0.9962  | 0.9992 | 0.9933 | 0.9956  | 0.9955  | 0.9984  | 0.9930  | 0.9965  | 0.9949  | 0.9978  | 0.9940  | 0.9966  |
| Sharpening | 0.9785  | 0.9910 | 0.9801 | 0.9908  | 0.9536  | 0.9708  | 0.9762  | 0.9899  | 0.9475  | 0.9628  | 0.9491  | 0.9652  |
very successful to optimize the MSF parameters in accordance with various regions of the test images. Additionally, the visual quality of the signed images and the robustness parameter NC are also found to be well balanced due to its use. We attribute this excelling performance of our scheme to the use of particle swarm optimization technique in collaboration with the objective function used.

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