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An Imperceptible Watermarking Scheme Using Spider Monkey Optimization in the Frequency Domain

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ABSTRACT

This study presents a robust and imperceptible blind watermarking system based on the frequency domain. Additionally, the approach is optimized using a meta-heuristic algorithm. The recommended technique involves applying the Discrete Wavelet Transform to the host picture to extract four sub-parts: diagonal, vertical, horizontal, and approximate. After that, the approximation sub-band is subjected to Singular Value Decomposition (SV-Decomposition). The optimal entrenching scaling factor used during the watermark (WM) implanting procedure is obtained by the SMO technique. Peak Signal-to-Noise Ratio (PSN-Ratio) assesses perceptibility quality, whereas Normalized Cross Correlation (NC) evaluates the robustness of the watermarked picture. Testing the presented process on watermarked images with a range of attacks yields decent PSN-Ratio and NC values.

Introduction

It is quite simple to manipulate multimedia data these days. Digital assets may be tempered and owned using sophisticated software. Many image security procedures have been developed to stop illegal copying of digital data, and one of the most successful of them is the digital watermarking method [1]. The primary objective of the watermarking approach is to incorporate digital data into digital content, including text, music, movies, and photos. An optimization approach is used to calculate the scaling factor [2]. Both visible and invisible digital watermarks are possible. A visible watermark (WM), which is present on the host media, is not entirely transparent. This WM is frequently used to prevent copyright violations in digital files. In the case of the invisible watermarking approach, only specialized methods can be used to retrieve the invisible watermark. The primary purpose of the invisible watermark is data authentication [3]. The watermarking technique requires payload, resilience, and imperceptibility. Imperceptibility indicates that the entrenched and carrier images should be identical. A watermarking system is said to be robust if it can resist hacker attacks. Payload refers to the amount of data that is contained within the cover picture [4,]. Although transformation domain techniques are quite difficult, they are resistant to a number of assaults, whereas spatial domain approaches are less complex but not as robust. The original image's coefficients are reformed for implanting the WM in the transform domain [6].

The following sections provide the document's remaining structure: Section 2 delivers the description of the latest developments in image watermarking. In Section 3, the mathematical background is explained. Section 4 describes the methodology that is being presented. In Section 5, the analysis of the proposed method is performed, and in Section 6, the future views and conclusions are offered.

Literature Survey

This section provides an investigation of many Digital Image Watermarking (DIW) techniques that have been the focus of recent studies. Numerous optimization strategies have been used by researchers, such as fuzzy logic, neural network approaches, bioinspired algorithms, SVM (Support Vector Machine), etc. An approach utilizing SV_Decomposition for Integer Wavelet transformations is investigated in [7]. The correlation between a range of images before and after the attacks is imposed, is analysed to derive the fitness function. A time-efficient method for image watermarking was proposed by Sharma et al. [9]. The cover image is separated into 8 by 8 chunks using this method. After applying the DC-Transform to every block, the reference coefficient is chosen using a JPEG quantization table. Using this reference coefficient, a watermark is implanted. The approach is optimized using Ant Colony Optimization (ACO) Algorithm.

Abdulhammed et al. [10] introduced a Blue Monkey Algorithm (BMA)-based imperceptible digital watermarking approach. This method separates both the watermark and the cover image into two parts. At the point determined by BMA, the first segment of the carrier image contains the first portion of the WM picture. The second portion of the carrier image contains the second part of the WM picture.

Mathematical Background

The mathematical foundations used in the suggested approach are represented in this section.

Discrete Wavelet Transform (DW-Transform)

DW-Transform splits the carrier image into four sub-components (LL1, LH1, HL1, and HH1), which are referred to as approximation, vertical, horizontal, and diagonal sub-bands, respectively. Fig1 shows the DW-Transform of Lena image.

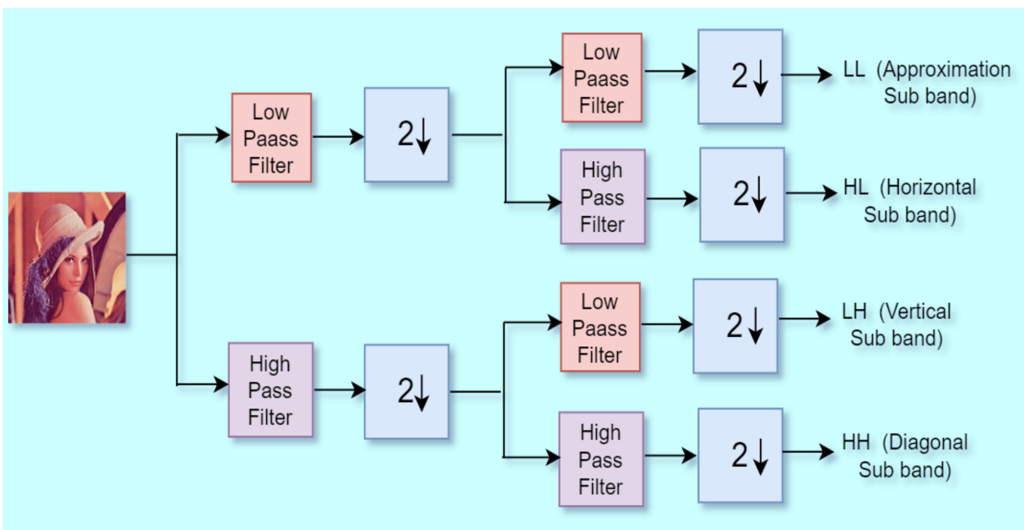

Figure 1: DW-Transform of Input Image for decomposing into sub bands

Singular Value Decomposition (SV-Decomposition)

SV-Decomposition is widely utilized in image processing methods, including image compression, image denoising, watermarking, steganography, etc. SV-Decomposition of an image provides three matrices U, S, and V. Following is the representation of the SV-Decomposition of an image Img.

$$\text{Img} = U \times S \times V^T \quad (1)$$

$$\text{Img} = \begin{bmatrix} u_{1,1} & \cdots & u_{1,q} \\ u_{2,1} & \cdots & u_{2,q} \\ \vdots & \vdots & \vdots \\ u_{p,1} & \ldots & u_{p,q} \end{bmatrix} \begin{bmatrix} s_{1,1} & \cdots & & 0 \\ 0 & s_{2,2} & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & \ldots & & s_{p,q} \end{bmatrix} \begin{bmatrix} v_{1,1} & \cdots & v_{1,q} \\ v_{2,1} & \cdots & v_{2,q} \\ \vdots & \vdots & \vdots \\ v_{p,1} & \ldots & v_{p,q} \end{bmatrix}^T \quad (2)$$

The horizontal features are represented by matrix U, while the vertical details are represented by matrix V. Additionally, the image's brightness and algebraic characteristics are determined by singular values. Slight variations in singular values have little effect on the perceptibility quality of the image. The first singular value, which is given in decreasing order, is far larger than the majority of the other singular values. It is possible to use SVD on both square and rectangular matrices [12].

Spider Monkey Optimization

The foundation of Spider Monkey Optimization (SM-Optimization) is the fission-fusion social structure that occurs during the foraging activity of spider monkeys. Spider Monkeys forage in small groups. The foraging route is selected by the female leader. The group leader (global leader) divides the group into subgroups to forage alone if she cannot find enough food. Each subgroup is controlled by a local leader, who also plans the day's foraging route. There must be a minimum of monkeys in each subgroup for SM-Optimization to work. Fusion time is defined as the number of groups in a subsequent fission that are less than the minimum number of monkeys.

SM-Optimization algorithm consists of various phases described as follows:

Initially, SM-Optimization creates a uniformly distributed group of M spider monkeys using the following equation:

$$SM_{mn} = SM_{minn} + U_i(0,1) \times (SM_{maxn} - SM_{minn}) \quad (3)$$

Where SM_{mn} represents the n^{th} dimension of the m^{th} Spider Monkey.

In the Local leader phase, update the location of each spider monkey using the following equation:

$$SMnew_{mn}=SM_{mn}+U_i(0,1)\times(LL_{kn}-SM_{mn})+U_i(-1,1)\times(SM_{rn}-SM_{mn}) \quad (4)$$

SMrn denotes the n^{th} dimension of the arbitrarily chosen Spider Monkey, while LLkn displays the n^{th} dimension of the local leader of the k^{th} group.

In the Global leader phase, update the location of each spider monkey using the following equation:

$$SMnew_{pq}=SM_{pq}+U_i(0,1)\times(GL_q-SM_{pq})+Ui(-1,1)\times(SM_{rq}-SM_{pq}) \quad (5)$$

The Global Leader is determined in the Global Leader Learning Phase based on the best performance of the whole swarm.

The Local leader is identified in the Local Leader Learning Phase by updating the position of each group member.

In the Local Leader Decision Phase, all of the swarm's members update their position either randomly or based on the global leader's experience, if the local leader is not updated until a certain limit count known as the Local Leader Limit (LLL).

In the global leader decision phase, when the number of groups is exhausted and the global leader's location is not changed, the global leader merges all of the smaller groups into a single group [13, 14].

Proposed Methodology

This section suggested a blind image watermarking approach that is robust and imperceptible. Ten test images with 512 by 512 dimensions were used as the host image in this work, while a binary image with 32 x 32 dimensions was used as the watermark logo.

There are two phases in the Digital image watermarking process: Embedding and Extraction. Spider Monkey Optimization has been used to optimize the method and get the scaling factor. The approach is optimized using the following objective function represented by equation (6)

$$\text{Objective Function} = \frac{N}{\sum_{i=0}^{N} NC(WM,\ WM^*)} \quad (6)$$

Where N is the total no. of attacks, the correlation between WM and WM^* is denoted by NC.

Embedding Process

This section explains how the embedding process is carried out using spider monkey optimization. Fig 2 shows the watermark embedding process.

Step 1: Apply DW-Transform to split the cover image (Img) into four subparts.

[cA1, cH1, cV1, cD1] = DW-Transform (Img) (7)

Step 2: Take the approximation component (cA1) and divide it into non-overlapping 4×4 blocks and arrange in ascending order. Embedding is performed on primary n*n blocks. A vector contains the index of selected blocks for the extraction process.

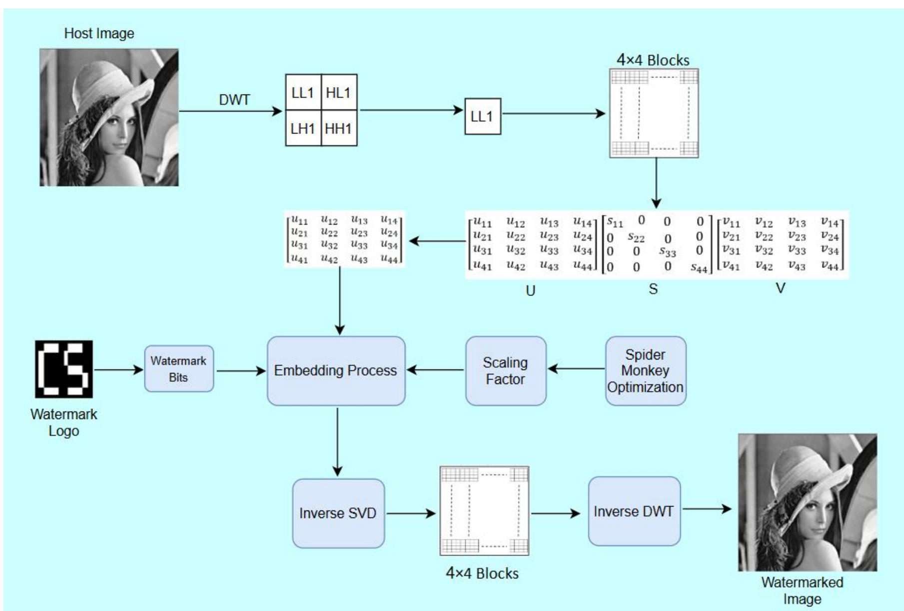

Figure 2: Watermark Embedding Process

Step 3: Apply SV-Decomposition on each selected block to get U, S, and V matrices.

Step 4: Matrix U is selected for embedding as it has a minor influence in terms of visible quality. **[15]**.

The coefficients of matrix U are modified as given below:

if Wk= 1 then MaxU = maximum(|U[-,1]|) $U_{2,1}$ = sign($U_{2,1}$) × (MaxU + φ) else MinU = minimum(|U[-,1]|) $U_{2,1}$ = sign($U_{2,1}$) × (MinU – φ) end

Here |U[-,1]| represents the absolute values of coefficients present in the first column, and φ is the scaling factor obtained by Spider Monkey Optimization Algorithm.

Step 5: Apply inverse SVD on each block.

Step 6: Combine all blocks to get the approximation (cA1) component.

Step 7: Apply inverse DWT to get the watermarked image as the output of this process.

Extraction Process

This section represents the inverse watermark embedding approach for extracting the WM from the watermarked image.

Step 1: Apply DW-Transform to split the cover image (Img) into four subparts.

[cA1, cH1, cV1, cD1] = DW-Transform(Img)

Step 2: Take the approximation component (cA1) and split it into non-overlapping 4×4 chunks. Select all chunks in which WM is embedded.

Step 3: Apply SV-Decomposition on each designated block [15].

Step 4: WM bits are extracted from the U component as given below: MaxU = maximum(|U[-,1]|) MinU = minimum(|U[-,1]|) D-Max = |MaxU -|$U_{2,1}$|| D-Min = |MinU -|$U_{2,1}$|| if D-Max <= D-Min then Wk' = 1 else Wk' = 0

Step 5: Assemble into a vector all of the extracted bits that were obtained in the preceding phase. The acquired picture is the extracted WM. Fig3 shows the Extraction process.

Experimental Results and Discussion

The presented method is executed on eight greyscale test images of dimension 512 × 512, are shown in **Fig. 4**. The presented scheme is executed on Python 3.11 with an Intel CORE i3 Processor and RAM of 4 GB. To determine the effectiveness of the projected method, the PSN-Ratio is used to assess the perceptual quality between the embedded picture and the original picture.

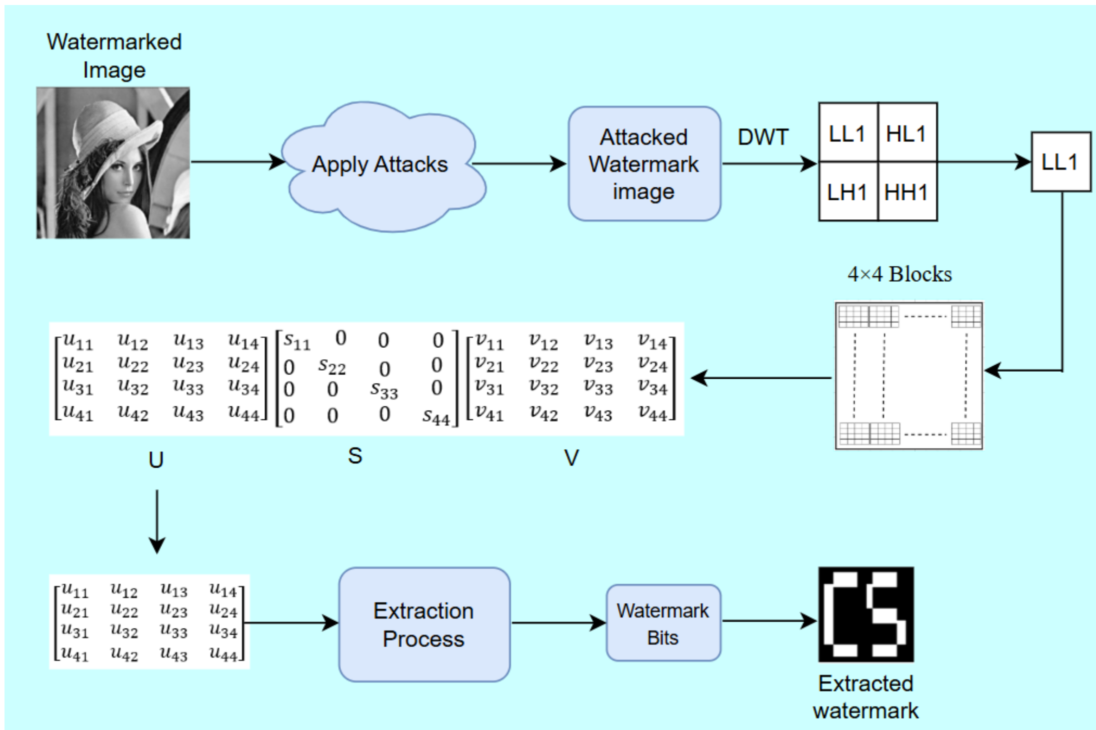

Figure 3: Watermark Extraction Process

To determine the robustness, NC is employed. PSN-Ratio = $10\log_{10}\left(\frac{255^2}{MSE}\right)$ (8)

PSN-Ratio is measured in decibels (dB). MSE= $\frac{1}{RS}\sum_{p=0}^{R-1}\sum_{q=0}^{S-1}\left[I_{img}(p,q) - I'_{img}(p,q)\right]^2$ (9)

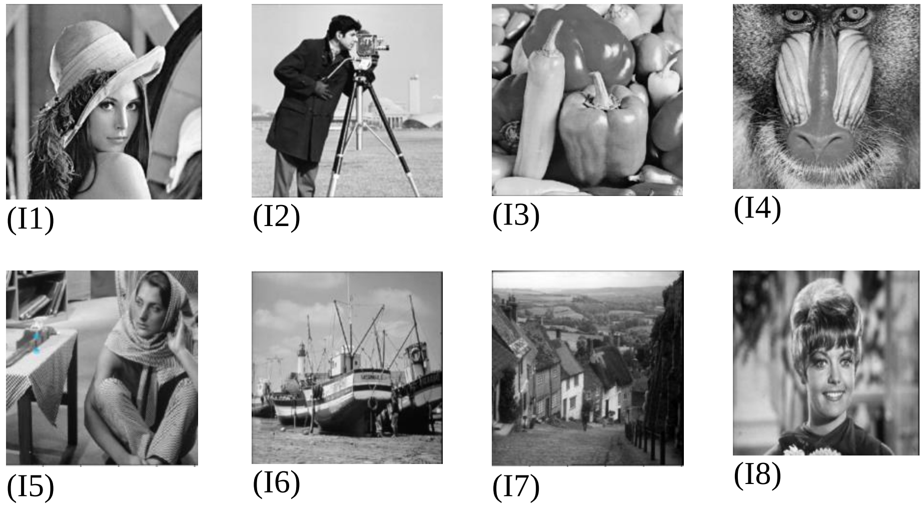

Figure 4: (I1) Lena (I2) Cameraman (I3) Pepper (I4) Baboon (I5) Barbara (I6) Boat (I7) Goldhill (I8) Zelda

Here, I_{img} signifies the original host image and I'_{img} signifies the watermarked image.

$$NC=\frac{\sum_{p=1}^{R}\sum_{q=1}^{s} WM(p,q)\times WM'(p,q)}{\sum_{p=1}^{R}\sum_{q=1}^{S} WM^2(p,q)} \qquad (10)$$

Where WM denotes the original watermark and WM' represents the extracted watermark.

Fig. 5 shows the extracted watermark from the distorted Lena image using various attacks given in Table 1.

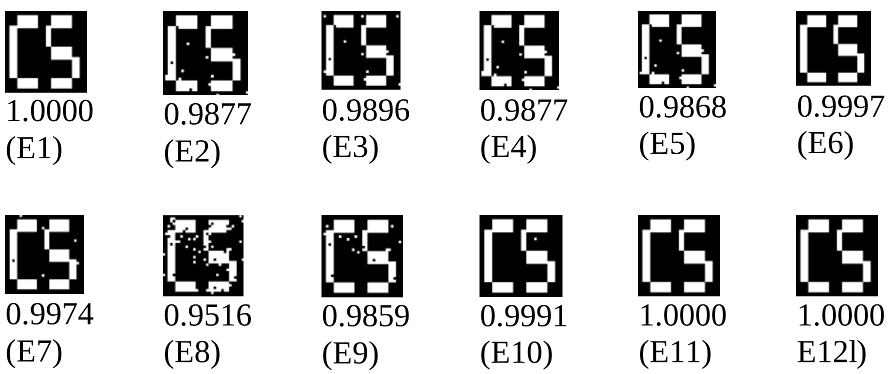

Figure 5: Extracted Watermark from Lena image (E1) NA (E2) SH (E3) MF (E4) AF (E5) GF (E6) JPEG (E7) S&P (E8) RT (E9) CR (E10) HE (E11) GC (E12) GN

Table 1 represents the comparative study of NC values between the reference study and Lena image. Table 2 shows the analysis of PSN-Ratio values with other techniques [16].

Table 1: Analysis of NC values of Lena image with other techniques

Attack	Proposed DWT+SVD+SMO	DWT+SVD+Firefly Algo [5]	HMD+SVD+PSO [8]	DWT+SVD + PSO [11]
No Attack (NA)	1.0000	1.0000	1.0000	0.9994
Sharpening (SH)	0.9877	1.0000	0.9964	0.9982
Median Filter (MF) (3×3)	0.9896		0.9999	0.9696
Average Filter (AF) (3×3)	0.9877		0.9999	
Gaussian Filter (GF) (3×3)	0.9868			0.9773
JPEG Compression (50)	1.0000	1.0000	0.9998	0.9828
Salt & Pepper Noise (S&P) (.01)	0.9974	0.9450	0.9999	0.9937
Rotation (RT) 45^0	0.9516		0.9509	
Cropping (CR) ¼ left up	0.9859	0.9491	0.9865	0.9980
Histogram Equalization (HE)	0.9991	0.9973		0.9932
Gamma Correction	1.0000	1.0000		0.9992
Gaussian Noise (.001)	1.0000	0.9853	0.9999	0.8235

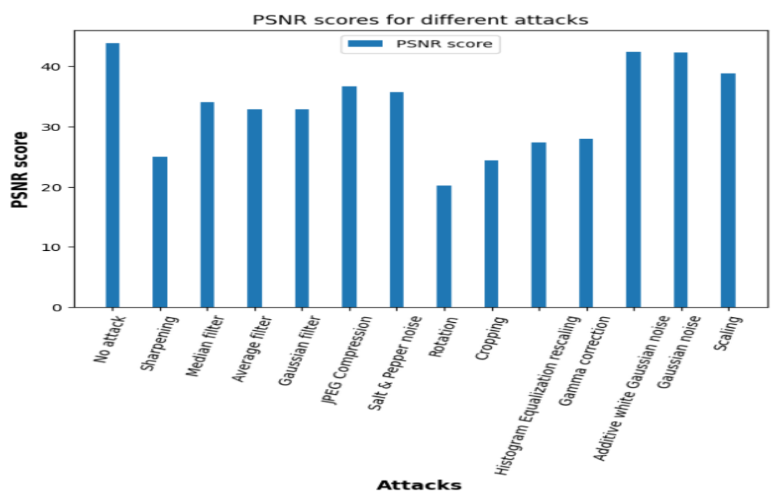

Figure 6: PSNR Score after various attack

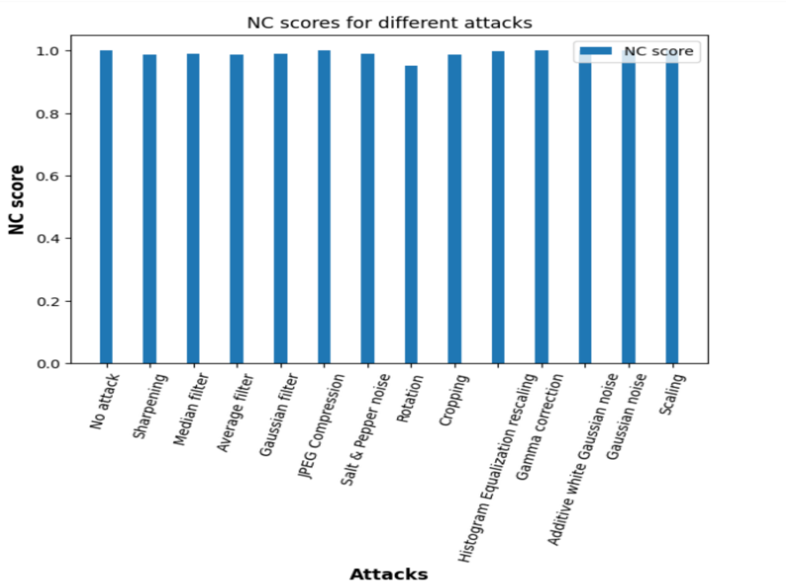

Figure 7: NC values after various attack

Conclusions

The presented scheme is an imperceptible blind watermarking approach using bio inspired algorithm known as spider monkey optimization. In this approach carrier image is transformed into the frequency domain using DW-Transform, and then SV-Decomposition is imposed on approximation subband (LL1). The WM is embedded into the coefficients of U matrix. The scaling factor for optimizing the algorithm is computed by the spider monkey optimization algorithm. Various attacks were performed to examine the effectiveness, significance and resilience of the suggested strategy. A remarkable perceptual quality has been received by the proposed scheme. The proposed technique has achieved PSN-Ratio greater than 40dB and NC value closer to 1. In the future, the proposed scheme can be improved in terms of security by using an encryption algorithm.

Table 2: Comparison of PSNR values with other techniques

Test Image	Proposed DWT+SVD+ SMO	DWT+SVD+ Firefly Algo [5]	HMD+SVD +PSO [8]	DWT+S VD+ PSO [11]
Lena	45.9783	45.5527	48.8785	43.3281
Camera man	50.1912	44.1393	-----	-----
Baboon	40.5783	42.6448	48.9063	40.0337
Goldhill	45.5011	-----	48.9170	-----
Pepper	45.2957	45.4207	44.9753	40.0008
Barbara	44.1648	41.8801	44.9604	51.4001
Boat	48.9481	41.0978	-----	-----
Zelda	43.2572	42.4509	-----	44.1803

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