RESEARCH PAPER

A Blind Robust and Imperceptible Image Watermarking Technique Using the Bio-inspired Algorithm in the Wavelet Transform

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ABSTRACT

This study introduces a resilient and imperceptible Digital Image Watermarking (DIWing) approach grounded on the frequency domain. Additionally, the approach is optimised using a meta-heuristic algorithm. The recommended approach is to use the Discrete Wavelet Transform (DWTrans) on the Cover Image (CI) in order to extract four sub-bands: diagonal, vertical, horizontal, and approximation. After that, the approximation sub-band is subjected to Singular Value Decomposition (SVDecom).

The optimal entrenching scaling factor used during the watermark (WM) implanting procedure is obtained by the Spider Monkey Optimisation (SMO) technique. Peak Signal-to-Noise Ratio (PSN-Ratio) assesses perceptibility quality, whereas Normalised 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.

Keywords: Singular Value Decomposition (SVD), Digital Image Watermarking (DIW), Spider Monkey Optimisation (SMO), Discrete Wavelet Transform (DW-Transform)

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1. 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]. In the watermarking approach, a digital watermark is incorporated into digital content, including text, music, movies, and photos. An optimisation 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 specialised 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 Coefficients of the OHI are transformed to implant the WM in the transform domain [6]. Fig. 1 shows the digital watermarking system.

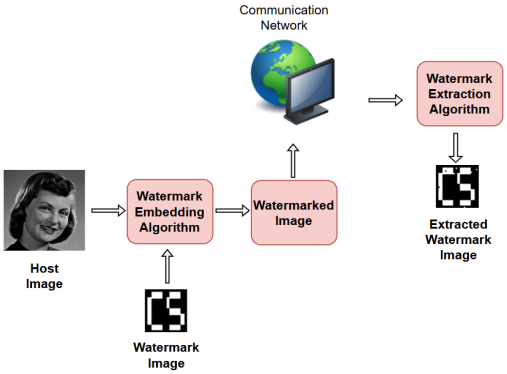


Fig. 1 Digital Watermarking System

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. Section 5 explains the performance analysis of the proposed system, and Section 6, offers future views and conclusions.

2. Literature Survey

This section provides an investigation of many Digital Image Watermarking (DIW) techniques that have been the focus of recent studies. Numerous optimisation strategies have been used by researchers, such as fuzzy logic, neural network approaches, bioinspired algorithms, SVM (Support Vector Machine), etc. An approach utilising SV_Decomposition for Integer Wavelet transformations is investigated in [7]. The correlation between a range of images before and after the attacks is analysed to derive the fitness function. A time-efficient method for DIWing was introduced in[9]. The CI 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 quantisation table. Using this reference coefficient, a watermark is implanted. The approach is optimised using Ant Colony Optimisation (ACO) Algorithm.

An approach in [10] introduced a Blue Monkey Algorithm (BMA)-based imperceptible digital watermarking approach. This method separates both the watermark and the CI 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.

The new study is motivated by concerns about intellectual property theft as digital content transmission over the internet increases, as described in [12]. Rather than embedding the watermark image directly, the authors first encrypt it using a Residue Number System (RNS), with certain GA operators (like crossover and mutation) incorporated into the encryption process to strengthen it. The embedding itself uses a three-level DWTrans to divide the CI into different frequency sub-bands, with the encrypted watermark hidden inside these decomposed frames. The core security rationale is that even in the event of a successful attack that manages to extract something from the watermarked image, the extracted content remains encrypted and therefore useless to an attacker, protecting the underlying secret information. Content owners can later decrypt the extracted watermark to reveal the hidden proof of ownership, which the authors frame as being usable as evidence "in a court of law" for copyright disputes.

A safe digital picture watermarking method in the hybrid domain (DWTrans and SVDecom) is proposed in [13]. To preserve a balance between perceptual quality and resilience, the Harmony-Grey Wolf (H-Grey) optimisation process is used to select the scaling factor. Additionally, PSMD (Partitioning,

Substituting, Merging, Division), a unique symmetric cryptographic-based four-level encryption technique, is suggested to address UAV picture security issues by generating two random keys using the Fibonacci and prime number series.

In [14] a binary watermark is embedded into the LL3 sub-band of a DWT decomposition, with the singular values of that sub-band modified using multiple scaling factors (MSFs) rather than a single global factor. The MSFs are optimised using a newer Firefly variant called the Photinus search algorithm, named after a genus of firefly. The method was tested specifically on computed tomography (CT) images, a common medical imaging modality. Performance was measured with PSN-Ratio and normalized cross-correlation, evaluating both the perceptual quality of the watermarked image and its resilience after various attacks. The study frames its contribution primarily around achieving high performance specifically for the medical-imaging use case rather than general-purpose images. This paper is a good example of how algorithm-variant refinements (Photinus search vs. standard Firefly) are increasingly common as authors seek incremental improvements over well-established base algorithms.

A Hybrid Meta-Heuristic Color Image Watermarking (HMHCIW) algorithm for secure ownership protection of color images is given in [15]. It implants a WM into a color image and later retrieves it to verify image authenticity. The method uses a hybrid BFPSO optimisation technique. This algorithm optimises transform-domain coefficients for effective watermark embedding. The optimisation improves PSN-Ratio, preserving high perceptual quality of the watermarked image, and enhances resilience against various assaults. Overall, the scheme provides reliable authentication with strong imperceptibility and security.

The study presented in [16] applies Ant Colony Optimization within a medical, telemedicine-focused context, using a Ridgelet transform — a transform particularly well-suited to representing straight-line, directional features in images — combined with QR decomposition for the embedding step. A distinctive technical feature is the use of adaptive Quantization Index Modulation (QIM), a watermarking embedding technique distinct from the simple scaling-factor modification. ACO is used specifically to adaptively select the fractional parameters controlling this QIM-based embedding process, following ACO's more general role across this literature of navigating complex, structured parameter spaces using pheromone-guided path search. The scheme was designed and evaluated as blind, meaning original host images are not required for extraction, an important practical consideration for telemedicine deployment where the original image may not always be readily available at the receiving end.

To enhance imperceptibility, robustness, and embedding efficiency, a Chaotic Map-integrated Quantum-Inspired Multi-Objective Cuckoo Search (CMQICS)-based watermarking technique is recommended in [17]. The technique optimizes the watermark embedding process by cuckoo search algorithm. A multi-image watermarking technique is proposed in order to boost payload size and reduce perceptible distortion. Using a hybrid Discrete Cosine Transform (DCTrans), 2D DWTrans and a zigzag scanning technique, the watermark embedding is carried out in the frequency domain. This hybrid architecture guarantees dependable watermark extraction while maintaining image quality and strengthens resistance against different image processing threats.

A reliable medical image watermarking technique utilizing SVDecom in the DWTrans domain is presented in [18]. Second-level DWTrans is applied first to break down the medical image, and then SVDecom is used to both the WM and the chosen frequency sub-band. Watermark strength is optimized using Bacterial Foraging, Genetic Algorithm, and Particle Swarm Optimisation. A fitness function is used to assess their performance under various assaults.

3. Mathematical Background

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

3.1. 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. DWTrans of the Lena image is shown in Fig. 2.

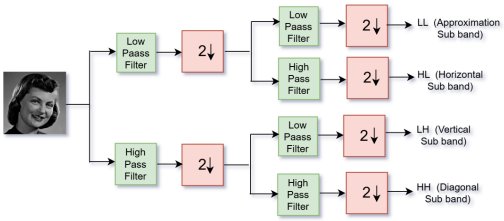


Fig. 2 DW-Transform of Input Image for decomposing into sub-bands

3.2 Singular Value Decomposition (SVDecom)

After applying the SVDecom to a CI, three matrices U, S and V are formed which are widely used in image processing techniques like image compression, image denoising, image watermarking, image steganography etc. The representation of the SVDecom of an image (Img) is:

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

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

The horizontal details are contained in matrix U and the vertical details are contained in matrix V. Additionally, the image's brightness and algebraic characteristics are determined by singular values. Just a few different values for the singular do not significantly affect the perceptual eminence of the image. The first singular value, which is listed in decreasing order, is significantly larger than most of the other singular values. It is possible to use SVD on both square and rectangular matrices [19].

3.3 Spider Monkey Optimisation

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

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

At first, SM-Optimization produces a uniformly dispersed set of M spider monkeys with the following equation:

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

Where SM_{mn} is the nth dimension of the mth Spider Monkey.

For the Local leader phase , modify the native position of every 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 is the nth element of the arbitrarily selected Spider Monkey and LLkn is the nth element of the local leader of the kth cluster.

During the Global leader phase, move every spider monkey to a new location founded on the equation below.

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

The Global Leader is selected in the Global Leader Learning Phase, based on the best performance of the entire swarm.

In the Local Leader Learning Phase, every cluster member's position is updated to determine the Local leader.

All the members of the swarm update their position in a random manner or according to the position of the global leader, if the local leader is not updated until a predetermined

number of time ticks is reached, called the Local Leader Limit (LLL).

A global leader: when the number of clusters is depleted and the location of the global leader is not updated the global leader combines all the smaller clusters into one cluster [20,21].

4. Proposed Methodology

This section suggests a blind image watermarking approach that is robust and imperceptible. Ten test images with 512 by 512 dimensions were used as the host images 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 Optimisation has been used to optimise the method and get the scaling factor. The approach is optimised 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.

4.1. Embedding Method

The embedding method is implemented using the spider monkey optimisation is explained in this section. The WM embedding method is shown in Fig. 3.

Step 1: Apply DW-Transform to split the CI into four subparts.

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

Step 2: Take the approximation component (cA1) and divide it into non-overlapping 4×4 blocks and arrange in ascending order. The first n*n chunks are used for embedding. The designated chunks for extraction are stored in a vector.A vector is used to store the index of selected blocks for the extraction process.

Step 3 – Compute matrices U, S and V using SVD, for selected blocks.

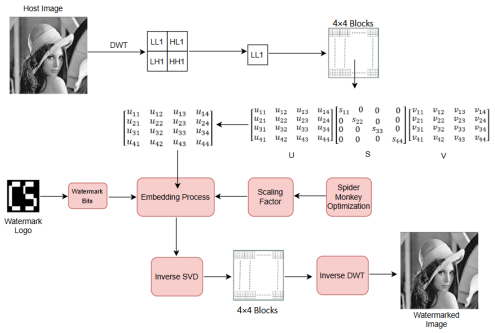


Fig. 3 Watermark Embedding Process

Step 4: This is a step in which the matrix U is selected to be embedded, as it has less effect on the visible quality [22].

The coefficients of matrix U are modified as given below:

if Wk= 1 then

Max1U = maximum(|U[-,1]|)

$U_{2,1} = \text{sign}(U_{2,1}) \times (\text{Max1U} + \varphi)$

else

Min1U = minimum(|U[-,1]|)

$U_{2,1} = \text{sign}(U_{2,1}) \times (\text{Min1U} - \varphi)$

end

Here |U[-,1]| specifies the absolute values of the coefficients in the first column, and φ is the scaling factor generated by the Spider Monkey Optimisation Algorithm.

Step 5: For every block, use inverse SVDecom.

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

Step 7: The result of this process is the watermarked image which is achieved by inverse DWTrans in this step.

4.2. Extraction Process

This section represents the inverse watermark embedding approach for extracting the WM from the result obtained in the embedding process.

Step 1: Use DW-Transform to split the CI into four subparts.

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

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 SVD on each designated block.

Step 4: WM bits are extracted from the U component as given below:

Max1U = maximum(|U[-,1]|)

Min1U = minimum(|U[-,1]|)
DMaxx = |Max1U -|$U_{2,1}$||
DMinn = |Min1U - |$U_{2,1}$||
if DMaxx <= DMinn then
Wk' = 1
else
Wk' = 0

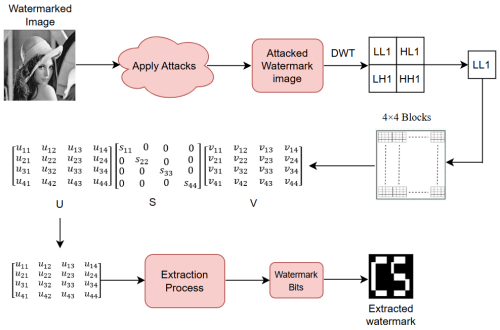


Fig. 4 Extraction Process of Watermark

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. Fig. 4 shows the Extraction process.

5. Empirical Findings and Discussion

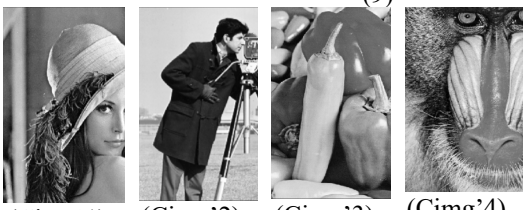
The developed method is evaluated using eight test images of dimension 512 × 512 of grayscale as depicted in Fig. 5. The proposed scheme is executed using Python 3.11, Intel CORE i3 Processor and 4 GB of RAM. The PSN-Ratio is used to assess the perceived quality of the embedded image, and the CI to determine the efficiency of the projected approach.

For determining the resilience, NC is employed.

$$\text{PSN-Ratio} = 10\log_{10}\left(\frac{255^2}{MSE}\right) \quad (8)$$

PSN-Ratio is measured in decibels (dB).

$$\text{MSE}=\frac{1}{\text{RS}}\sum_{p=0}^{R-1}\sum_{q=0}^{S-1}\left[I_{img}(p,q)-I'_{img}(p,q)\right]^2 \quad (9)$$



(Cimg'1) (Cimg'2) (Cimg'3) (Cimg'4)



(Cimg'5) (Cimg'6) (Cimg'7) (Cimg'8)

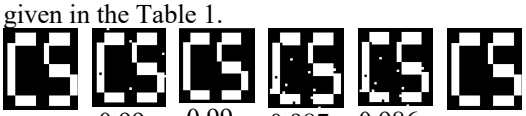
Fig. 5 (Cimg'1)Lena (Cimg'2)Cameraman (Cimg'3)Pepper (Cimg'4)Baboon (Cimg'5)Barbara (Cimg'6)Boat (Cimg'7)Goldhill (Cimg'8)Zelda

Here, I_{img} signifies the CI, and I'_{img} signifies the resulting watermarked image.

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

Where WM denotes the watermark to be embedded and WM' represents the retrieved watermark.

Fig. 6 shows the retrieved watermark from a distorted Lena image using several assaults given in the Table 1.



1.0000 (E1) 0.9977 (E2) 0.9996 (E3) 0.9877 (E4) 0.9868 (E5) 1.0000 (E6)



0.9974 (E7) 0.9516 (E8) 0.9859 (E9) 0.9991 (E10) 1.0000 (E11) 1.0000 E12l)

Fig. 6 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 displays the analysis of PSN-Ratio values with other techniques. Fig. 7 represents the PSN-Ratio score after various attacks, and Fig. 8 represents the NC values of several attacks.

Table 1: Analysis of NC Values of Lena Image Across Various Techniques

Imposed Attack	Proposed	DWT+	HMD+	DWT+SVD+

	DWT + SVD +SMO	SVD + Firefly Algo [5]	SVD + PSO [8]	PSO [11]
No Attack (NA)	**1.0000**	1.0000	1.0000	0.9994
Sharpening (SH)	0.9977	**1.0000**	0.9964	0.9982
Median Filter (MF) (3×3)	**0.9996**		0.9989	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	0.9899	0.9737
Rotation (RT) 45^0	**0.9516**		0.9509	
Cropping (CR) ¼ left up	0.9859	0.9491	0.9865	**0.9980**
Histogram Equalisation (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

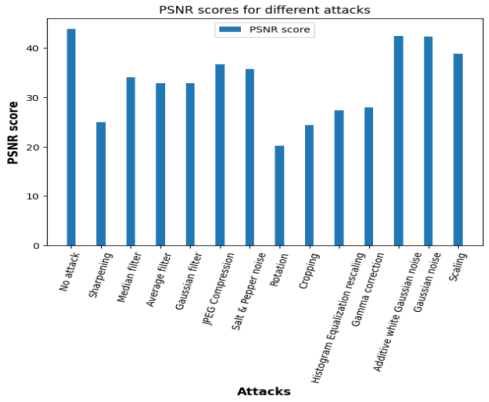


Fig. 7 PSNR Score after various attack

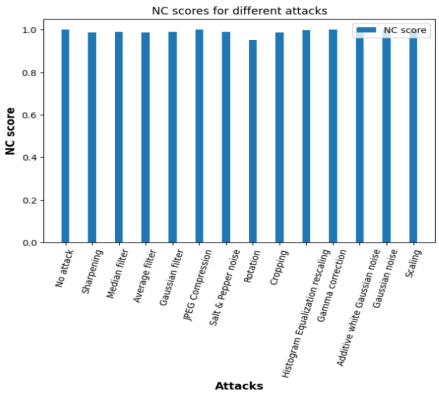


Fig. 8 NC values after various attacks

6. Conclusions

The presented scheme is an imperceptible blind watermarking approach using a bio-inspired algorithm known as spider monkey optimisation. In this approach, the carrier image is changed by transforming the signal to its frequency domain through the DWTrans and at that point SVDecom is employed to the approximation subband (LL1). The WM is embedded into the coefficients of U matrix. The scaling factor for optimising 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

Table2: Comparison of PSNR values with other techniques

Test Image	Proposed DWT+ SVD	DWT+ SVD +Firefly Algo	HMD +SVD +PSO [8]	DWT+ SVD+ PSO [11]

	+SMO	[5]		
Lena	45.9783	45.5527	**48.8785**	43.3281
Cameraman	**50.1912**	44.1393	-----	-----
Baboon	**48.5783**	42.6448	47.9063	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	**44.6572**	42.4509	-----	44.1803

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.

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