PSO-Optimized Watermarking Using Lifting Wavelet Transform and SVD for Enhanced Image Security

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Abstract – A significant data protection technique for a number of problems, the most prominent being identity authentication and copyright protection, is digital image watermarking. The rapid digital transformation of the world has given rise to a variety of vision modification techniques, which have significant consequences for picture data security. As a result, maintaining the validity and integrity of digital images is crucial, which is why researchers are focusing on creating effective watermarking techniques. This study proposes an optimized robust watermarking technique based on lifting wavelet transform (LWT) with singular value decomposition (SVD) using the particle swarm optimization (PSO) algorithm for achieving multiple scaling factors (MSF). To increase security and durability, cover images are exposed to numerous attacks. The evaluation criteria, which encompass normalized cross-correlation (NCC) and peak signal-to-noise ratio (PSNR), were used to compare our outcomes with those of leading watermarking methods. The comparison reveals that our proposed strategy surpasses existing methods in terms of both robustness and imperceptibility. The results suggest that this technique is suitable for tamper detection in various domains, including cryptography, medical imaging and multimedia transmission.

Keywords – Watermarking; Singular Value Decomposition; Lifting Wavelet Transform; Peak Signal-To-Noise Ratio and Particle Swarm Optimization.

I. INTRODUCTION

In recent years, robust watermarking has embraced a variety of optimization techniques to allow for the autonomous change of its primary operational parameters, hence enhancing its performance [1]. The protection of videos from digital piracy is therefore one of the most important problems facing the industry and innovators alike. The advancement of low-cost storage systems and fast connection technologies is also driving the need for the use of photographs and videos. Securing digital information during communication is becoming crucial [2]. Sensitive or valuable messages should often be kept buried in multimedia content. Watermarking is a crucial tactic for safeguarding significant e-multimedia data and intellectual property [3]. Watermarking techniques are used for numerous purposes, including ownership protection, however they are less common when compared to other functions like authentication and localization [4]. The practice of digital watermarking involves putting a watermark to a host image or video so that the encoded digital signature may be retrieved in the event that information about the identity of the media owner is required [5].

The invisible watermarking is the most widely employed form of copyright protection applications. Digital watermarking has been applied to a number of other uses than copyright protection, such as content authentication, copy control, broadcast monitoring, and tamper detection [6]. Since they may meet watermarking objectives including robustness and effective imperceptibility, many frequency domain-based image watermarking systems have been described recently [7]. Several transformations, including discrete wavelet transform (DWT) [8], discrete cosine transform (DCT) [9], discontinuous wavelet transform (LWT) [10], discrete SVD [11], and Hessenberg decomposition [12], are used in the robust watermarking process. The watermarking process is made more resilient by using a variety of optimization algorithms. The two most often utilized algorithms are particle swarm optimization (PSO) [13] and firefly optimization [14]. This paper proposes a resilient watermarking system using the PSO algorithm in conjunction with LWT-SVD.

The rest of the paper is prepared as follows. The related works of watermarking schemes based on various transformations and optimization algorithms is discussed in Section II. Section III outlines the preliminaries and the proposed scheme for robust and secured watermarking process. The results and various ablation methods are tested and discussed in section IV followed with concluding remarks in section V.

II. RELATED WORKS

The study of conventional image watermarking has only looked at standard mathematical formulations like DCT, DWT, and SVD, as well as its hybrid versions like DCT–DWT, DCT–SVD, and DWT–SVD. Statistical computations are used to embed watermark into the host images. Typically, watermark embedding stability is dependent on a single scale value. The degree of change caused by watermark in the original images is indicated by embedding strength, sometimes referred to as the scaling factor.

Cox et al. asserted that as some spectrum components can be more or less resistant to change, SSF would not be the best method for changing every cover picture coefficient [15]. Alternatively, they suggest using MSFs or different values of the scaling factor. Finding the optimal MSF values to get the best outcomes, however, is the main problem. Image watermarking is becoming more and more important from multiple angles in the multimedia quantitative approach. Several soft computing approaches are adapted to increase the durability of the embedding process without compromising visual quality of the signed image. Robustness is assessed after watermark extraction based on how similar the recovered parameters are to the original set of values. For many years, SVD (singular value decomposition) has been used as a novel watermarking technique [16]. It provides a typical, recognizable depiction of an image's changes along with structural information that is essential for estimating image quality. Singular vectors are better at expressing structural information in terms of their physical meaning. Singular values, which often characterize image brightness, are associated with singular vector alterations.

Several surveys have been carried out on SVD with different transforms for watermarking techniques [17-19]. Li et al. introduced a multiple watermark embedding approach that included DWT and DFT, the coefficients of which were employed as feature vectors to improve robustness [20]. Hu et al. proposed a DWT-DCT domain collective blind picture watermarking system with adaptive embedding strength driven by quality parameters [21]. Kazemivash and colleagues developed a strong digital picture watermarking technology based on the LWT [22]. Liu et al. developed the discrete fractional angular transform (DFAT) to enhance the robustness when compared with DFRNT [23].

In addition to this, several researchers have developed evolutionary algorithms-based transformation for watermarking techniques. Loukhaoukha et al. used metaheuristic approach in the LWT–SVD domain to determine MSF values [24]. As previously stated, integrating evolutionary techniques such as PSO [13], bacterial foraging [27], firefly algorithm [28], ant colony optimization, differential evolution and genetic algorithm with transformation algorithms can solve the challenge of determining the optimal values of multiple scaling factors (MSFs). In this work, LWT–SVD hybrid transform is employed to insert watermarks and optimization of MSFs are performed by PSO algorithm.

III. PROPOSED WORK

Lifting Wavelet Transform (LWT)

The existing methods for watermarking that rely on basic wavelet transforms have considerable drawbacks. Due to the floating-point approach used in typical wavelet transformations, the system's limited capacity to handle finite word lengths will result in rounding errors, making it impossible to recreate the original signal. Moreover, the conventional wavelet transform technique requires sophisticated computing facilities, which adds complexity and expense to the hardware implementation. In order to get over these problems, Sweldens [30] initially modelled LWT, also known as inverse wavelet transform (IWT), which is superior to previous transformations for use in watermarking applications. **Fig 1** displays the LWT block diagram. The steps involved in LWT are,

Split

Divides the original signal $r(n)$ for overlapping even $r(e)$ and odd samples $r(o)$.

$$r(e) = r(2n). \tag{1}$$

$$r(o) = r(2n + 1). \tag{2}$$

Predict

Correlation between even and odd samples is performed attaining prediction result.

$$p(n) = r(o) - P(r(e)). \tag{3}$$

where $p(n)$ is the difference between predicted and original image samples.

Update

Based on predicted signal $p(n)$, samples are updated.

$$q(n) = r + U(r(e)). \tag{4}$$

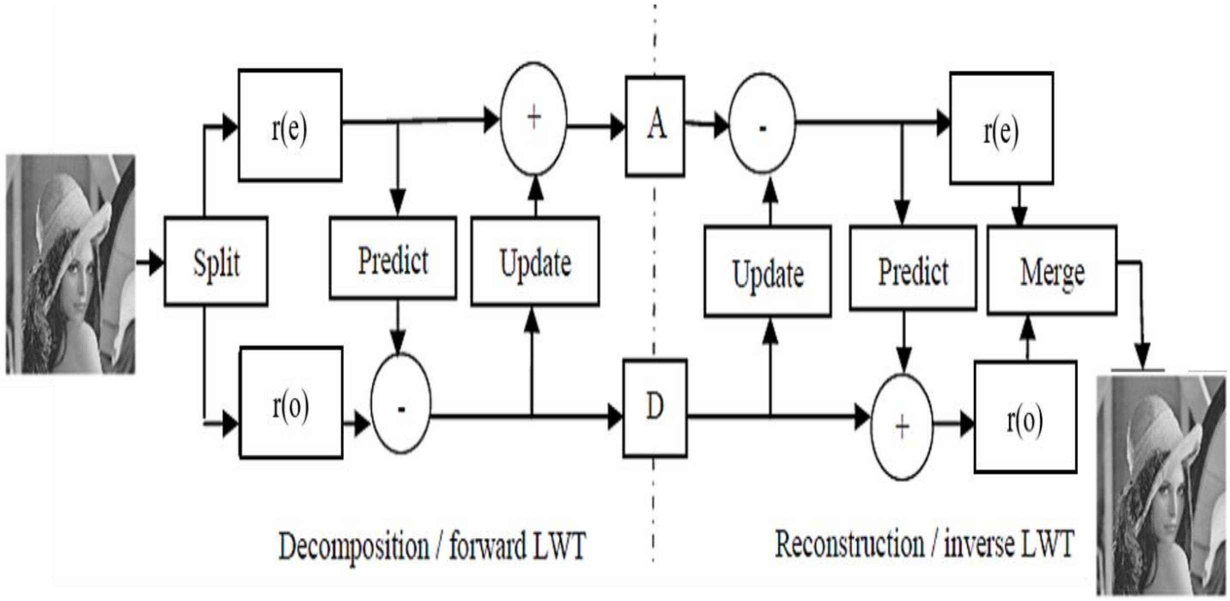

Fig1. Decomposition and Reconstruction of LWT.

Singular Value Decomposition

A digital image can be seen as a matrix from the standpoint of image processing, with pixel intensity values acting as matrix components. As a result of its unique qualities, SVD, a linear algebraic tool, can be employed in digital watermarking. Let M be the matrix with $u \times v$ can be represented as,

$$M = I \times J \times K^T. \tag{5}$$

where *I* and *K* are the orthogonal matrices with singular vectors. *J* is the diagonal matrix with values of *M*. The use of SVD in digital image processing has many benefits. The first advantage is that any image, regardless of size or matrix, may be treated using SVD. The second benefit is that there is little impact on the cover image's single values during conventional image processing. An additional benefit is that the singular values have inherent algebraic characteristics. Due to its unique values, SVD has certain disadvantages, such as low imperceptibility for watermarked images. The actions listed below can help you avoid this issue.

With embedded watermarks (W) and embedded factor (a), the matrix is given by,

$$M + aw = I_{ww} \times J_{ww} \times K_{ww}^T. \tag{6}$$

$$W = IJ_{ww}K^T. \tag{7}$$

Particle Swarm Optimization (PSO)

PSO is a metaheuristic approach [46] inspired from the swarm behaviour of birds flocking and so on. PSO is concerned with shifting the particle's velocity throughout the search space to 'p_{best}' and 'l_{best}'. Individual particles in each generation will have their unique 'l_{best}' and 'g_{best}' values. Keeping track of the 'g_{best}' and 'p_{best}' values, each particle travels towards the best result in the search space. PSO communicates information such as 'g_{best}', 'p_{best}', updated velocity, and location to every particle in the search space. The flowchart of PSO algorithm for watermarking is shown in **Fig 2**.

$$\vartheta_n(t+1) = \mu.\vartheta_n(t) + \sigma u_1(p_n - x_n) + \varphi u_2(g_n - x_n) \tag{8}$$

$$\rho_n(k+1) = \rho_n(k) + \vartheta_n(k+1) \tag{9}$$

where, u_1 and u_2 are acceleration constants; μ – weighted inertia parameter; t – iteration; $\sigma \approx 0.1\sim1$; $\varphi \approx 0.1\sim0.7$; p_n and g_n are the highest values for nth particle and each particle respectively.

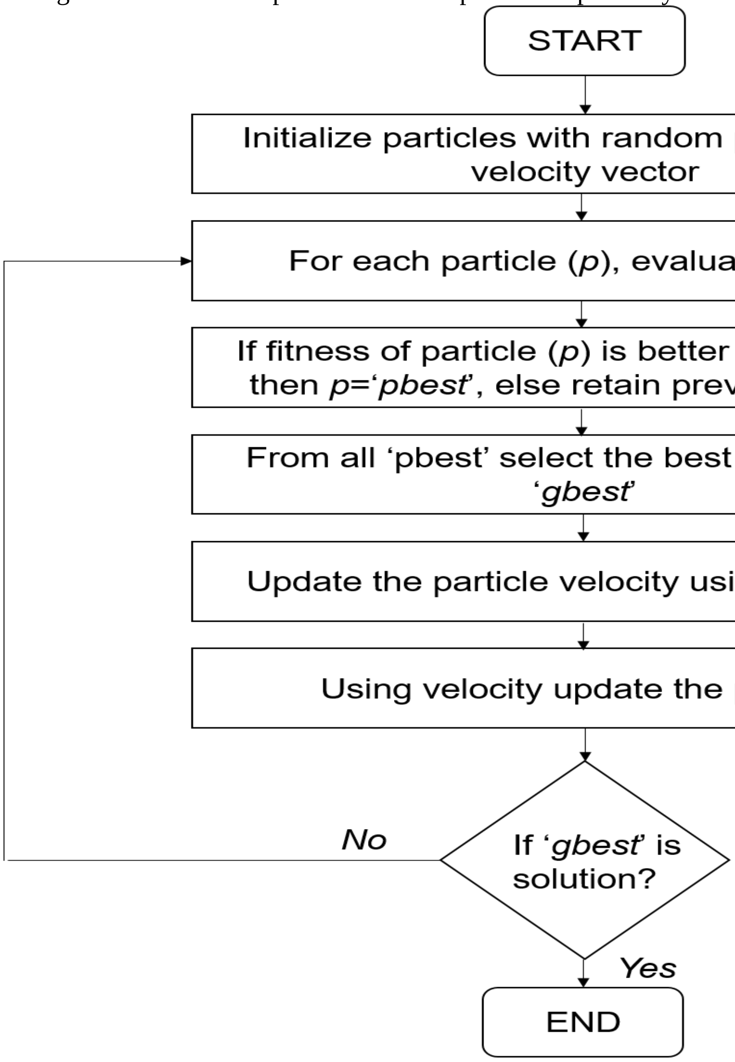

Fig 2. Flowchart of PSO Algorithm**.**

Impact Of Scaling Factors

The trade-off between robustness and imperceptibility is measured by scaling factors such as single scaling factor (SSF) and multiple scaling factor (MSF). Cox et al. stressed SSF is not suitable for defining all coefficients and should be replaced by MSFs. The effect of scaling factors is explained in [14]. To analyze scaling factors on PSNR and NCC(W, W') for proposed watermarking scheme are given in Eq. 10 and Eq. 11 respectively.

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

$$NC(W,W') = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}[W(i,j)\ W'(i,j)]}{\sum_{i=1}^{m}\sum_{j=1}^{n}[W(i,j)]^2} \tag{11}$$

where, M_{max} is the maximum pixel value and MSE is mean square error.

LWT-SVM Based Watermarking Scheme

The proposed watermarking procedure is shown in **Fig 3**. In the proposed scheme, false positive problem is avoided by with MSF with PSO algorithm. An improved method is developed by changing the Eigen values of LWT-SVD transformation which is represented in Eq. (12)

$$\lambda_n^a = \left\{1, \exp\left(\frac{-i2\pi a}{N}\right), \exp\left(\frac{-i4\pi a}{N}\right), \cdots, \exp\left(\frac{-2(n-1)i\pi a}{N}\right)\right\} \tag{12}$$

There are two watermarking images are employed shown in **Fig 4**. One with text watermarked and the other is watermarked without any texts.

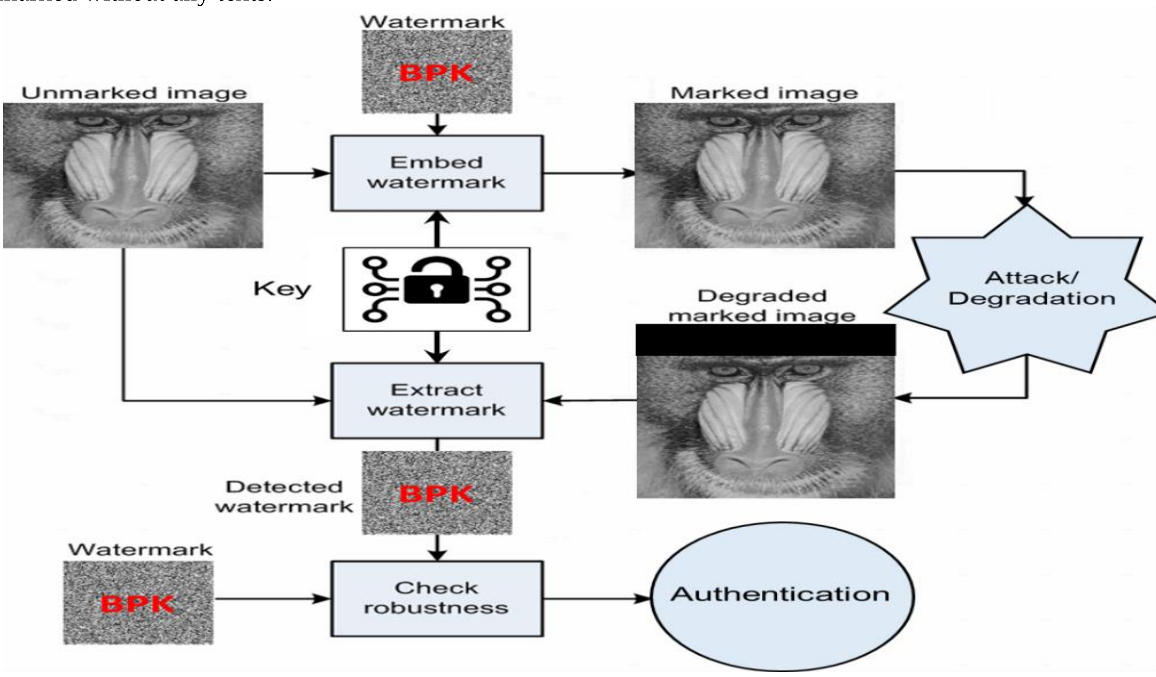

Fig 3. Proposed Method for Watermarking Procedure.

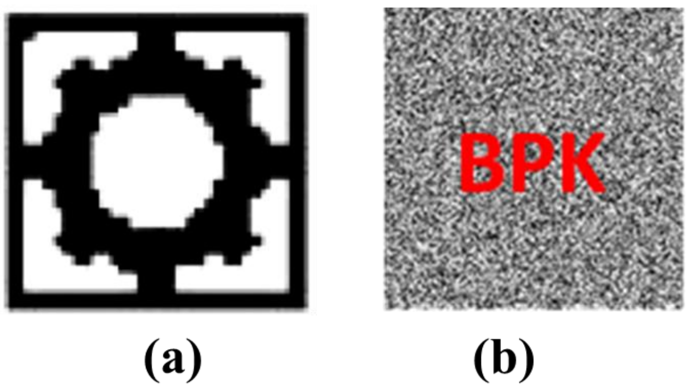

Fig 4. Watermarking.

IV. EXPERIMENTAL ANALYSIS

The scheme was implemented using MATLAB software, utilizing several standard 512x512 grayscale images for testing. In the proposed watermark embedding process, a 64×64 binary watermark is incorporated into the host image. The performance of the scheme is evaluated under various scenarios, focusing on imperceptibility and robustness. To accomplish optimal robustness to maintain imperceptibility, MSF are employed to adjust the coefficients during watermark embedding. The PSO method is used to determine the scaling factors. The inertia weight (μ) is designed to adaptively vary based on the number of iterations, with PSO parameters u_1 and u_2 set to 2. Additionally, the number of particles and iterations were set at 30 and 125, respectively, to manage computational overhead. The primary objective is to maximize robustness while keeping imperceptibility above a set threshold of 43 dB.

Analysis

When creating watermarking techniques for copyright protection, ensuring robustness is essential. Robustness measures how well an embedded watermark can resist different attacks. In this study, we tested the resilience of the proposed methods by applying eighteen distinct types of attacks to the watermarked images. An attack, in this context, is any image processing technique that can either remove or damage the embedded watermark. The attacks include the following: filtering (median, average, and Gaussian low-pass filters), noise addition (Gaussian white noise, salt & pepper noise, and speckle noise), and additional attacks (JPEG 2000 compression, histogram equalization, camera motion blur, sharpening attack and JPEG compression). **Fig 6** displays the watermarked Lena photos that were targeted using various techniques. **Table 1** shows PSNR and NCC Values Achieved for WM2 Using Single Scaling Factor (SSF). **Table 2** shows PSNR and NCC Values

Achieved for WM1 Using Multiple Scaling Factor (MSF). **Table 3** shows PSNR and NCC Values Achieved for WM1 With Optimized MSFs Using PSO Algorithm.

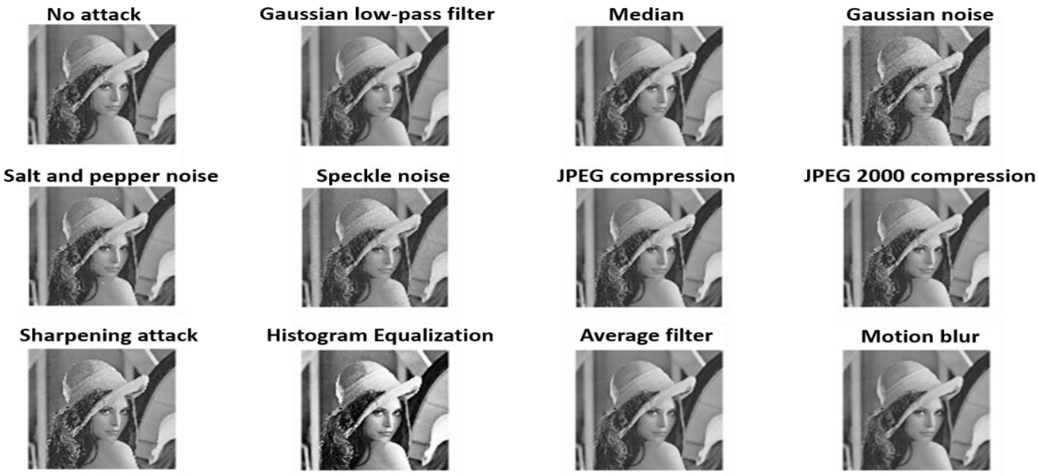

Fig 6. Lena Image With Attacks**.**

Table 1. PSNR and NCC Values Achieved for WM2 Using Single Scaling Factor (SSF)

Attacks	**PSNR and NCC values achieved by performing proposed method**							
	Lena		**Mandrill**		**Jetplane**		**Pepper**	
	PSNR	**NCC**	**PSNR**	**NCC**	**PSNR**	**NCC**	**PSNR**	**NCC**
No attack	45.5471	1	45.3873	1	45.4329	1	45.6801	1
Gaussian low-pass filter	44.0743	0.9991	45.1388	0.9985	46.9842	0.9963	45.9768	0.9746
Median	43.1769	0.9864	44.8272	0.9799	44.7628	0.9847	45.7389	0.9726
Gaussian Noise	43.8721	0.9986	44.3275	0.9967	44.1345	0.9943	44.2097	0.9964
Salt and Pepper noise	43.5862	0.9796	44.0827	0.9712	44.8726	0.9627	44.9731	0.9128
Speckle noise	43.0121	0.9418	44.0983	0.9371	44.9374	0.9572	44.7580	0.9598
JPEG Compression	44.7829	0.9958	44.7592	0.9474	45.0298	0.9738	44.9763	0.9876
JPEG 2000 Compression	43.9857	0.9837	44.0289	0.9741	44.1340	0.9478	45.0294	0.9474
Sharpening attack	45.7547	0.9827	45.7262	0.9462	44.8262	0.9827	44.8468	0.9362
Histogram Equalization	43.9827	0.9783	44.0192	0.9271	43.9129	0.9810	44.9281	0.9383
Average filter	43.6518	0.9681	44.5210	0.9918	44.9387	0.9277	45.0192	0.9824
Motion blur	45.9878	0.9888	43.9474	0.9367	44.2233	0.9478	44.0847	0.9827

Table 2. PSNR and NCC Values Achieved for WM1 Using Multiple Scaling Factor (MSF)

Attacks	**PSNR and NCC values achieved by performing proposed method**							
	Lena		**Mandrill**		**Jetplane**		**Pepper**	
	PSNR	**NCC**	**PSNR**	**NCC**	**PSNR**	**NCC**	**PSNR**	**NCC**
No attack	46.7542	1	46.0728	1	46.8271	1	45.9827	1
Gaussian low-pass filter	45.9037	0.9997	45.0482	0.9932	46.8421	0.9976	46.0988	0.9834
Median	44.9856	0.9864	45.7720	0.9873	45.2113	0.9892	46.3320	0.9837
Gaussian Noise	45.l028	0.9992	44.7876	0.9994	45.8347	0.9837	45.0382	0.9899
Salt and Pepper noise	45.0092	0.9736	44.7086	0.9736	45.9732	0.9922	44.9892	0.9734
Speckle noise	45.8472	0.9342	44.1284	0.9972	43.8492	0.9643	44.0482	0.9874
JPEG Compression	44.9278	1	44.2336	0.9999	44.7468	1	44.7120	1
JPEG 2000 Compression	45.8472	0.9993	44.9789	1	44.8472	0.9931	44.7099	0.9993
Sharpening attack	45.1098	0.9984	45.0012	0.9991	45.8543	0.9932	46.9764	0.9988
Histogram Equalization	45.7554	0.9965	44.7742	0.9967	44.9971	0.9722	45.0543	0.9987

Average filter	43.9022	0.9872	44.2389	0.96434	43.9093	0.9844	44.0013	0.9882
Motion blur	45.0381	0.9403	44.2996	0.9488	43.9841	0.9401	44.8532	0.9449

Table 3. PSNR and NCC Values Achieved for WM1 With Optimized MSFs Using PSO Algorithm

Cover Image	PSNR	NCC
Lena	44.8653	0.9973
Mandrill	45.7781	0.9991
Jetplane	44.5735	0.9988
Pepper	43.8762	0.9999

Results and Discussion

The results presented in **Table 4** demonstrate that our proposed scheme achieves a higher NCC value compared to other existing methods [32-33]. This confirms that our scheme effectively balances robustness and imperceptibility, outperforming previous approaches across all tested attacks. As discussed in Section 4, our objective function combines PSNR and NCC(W,W') values from both signed and attacked images in a linear fashion. This function is calculated considering eight different image processing operations. PSO utilizes this objective function to optimize the MSF used in the watermark embedding process. The optimized MSF is expected to improve robustness compared to the use of a SSF.

Table 4. Comparison of PSNR Values with Existing Works

Attacks performed	Existing methods			Proposed method
	TT. Takore et al. [32]	V.S. Verma et al. [33]	TT. Takore et al. [34]	
Gaussian low-pass filter	0.9990	0.9766	0.9980	0.9997
Median	0.9641	0.9570	0.9782	0.9864
Gaussian Noise	0.9772	0.9727	0.9942	0.9992
Salt and Pepper noise	0.9311	0.7464	0.9658	0.9736
Speckle noise	-	-	0.9236	0.9342
JPEG Compression (QF: 70%)	0.8925	1	1	1
JPEG 2000 Compression	-	-	1	0.9993
Sharpening attack	0.9853	0.9766	0.9987	0.9984
Histogram Equalization	0.9861	0.9297	0.9859	0.9965
Average filter	0.9491	0.8945	0.9798	0.9872
Motion blur	-	-	0.9036	0.9403

The suggested solution performs better than previous works with respect of PSNR values for attacking watermarks, as shown in **Table 4**. Our method shows excellent resilience against many kinds of additive noise, such as Gaussian noise with varying variances, Poisson, Speckle, and Salt & Pepper noise, based on the major results. Because of the MSF produced by chaotic sites, the suggested method effectively maintains PSNR and NCC values. The extensive experimental findings show that the proposed method provides improved performance and satisfies the required watermarking specifications, which makes it a good fit for many multimedia security applications.

V. CONCLUSION

Based on the LWT and SVD, this work provided a robust watermarking technique. The system employed an optimization methodology called the PSO method, which delivers enhanced MSF by attaining the ideal trade-off between robustness and imperceptibility, to select the best region of interest for watermark insertion. Numerous attacks were conducted on watermarked images in order to assess the resistance level; the results of the experiments indicate that the suggested approach yields the best PSNR and NCC value for the attacks carried out. The suggested approach offers noticeably more robustness and imperceptibility than the other documented techniques, according to the results of a comparison study with two other current schemes. The primary contribution of the suggested system is the multiple scale factor optimization achieved by PSO. The experimental results show that the embedding strategy is robust against specific image processing operations and that the suggested technique generates high PSNR values, suggesting good visual quality of signed and attacked images. It is discovered that the computed NC (W,W') scores for the eight different image processing assaults carried out in this work are suitably substantial. Adaptively choosing the optimal multiple scaling factors is one of the suggested technique's advantages; compared to other similar efforts, the results are optimal. It will be necessary to investigate and perform the time complexity computation for extraction and embedding in the future.

CRediT Author Statement

The authors confirm contribution to the paper as follows:

Conceptualization: Praveenkumar Babu, Supraja G, Gopi Kasinathan, Kavitha Devi K, and Yogapriya J; **Methodology:**

Kavitha Devi K and Yogapriya J; **Software:** Praveenkumar Babu and Yogapriya J; **Data Curation:** Praveenkumar Babu, Supraja G, Gopi Kasinathan and Kavitha Devi K; **Writing- Original Draft Preparation:** Praveenkumar Babu, Supraja G and Yogapriya J; **Visualization:** Praveenkumar Babu, Supraja G, Gopi Kasinathan, Kavitha Devi K, and Yogapriya J; **Investigation:** Gopi Kasinathan, Kavitha Devi K, and Yogapriya J; **Supervision:** Praveenkumar Babu and Kavitha Devi K; **Validation:** Praveenkumar Babu, Supraja G, Gopi Kasinathan, Kavitha Devi K, and Yogapriya J; **Writing- Reviewing and Editing:** Praveenkumar Babu, Supraja G, Kavitha Devi K, and Yogapriya J; All authors reviewed the results and approved the final version of the manuscript.

Data Availability
No data was used to support this study.

Conflicts of Interests
The author(s) declare(s) that they have no conflicts of interest.

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Competing Interests
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