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RESEARCH ARTICLE

Robust Digital Image Watermarking Using DWT, Hessenberg, and SVD for Copyright Protection

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ABSTRACT - With the rapid advancement of digital technology, protecting visual content against misuse, unauthorized copying, and forgery has become increasingly important. This study proposes a robust and secure image watermarking method that synergistically integrates Discrete Wavelet Transform (DWT), Hessenberg Decomposition (HD), and Singular Value Decomposition (SVD) to enhance both imperceptibility and robustness against common image attacks. The method involves embedding the watermark into the low-frequency coefficients obtained through DWT, leveraging HD for structural stability, and using SVD to embed the watermark into the singular values, ensuring minimal perceptual distortion. The approach is designed to withstand a wide range of attacks, including filtering, noise addition, cropping, and lossy compression, while maintaining high fidelity of the watermarked images. The implementation was tested on multiple grayscale images, such as Lena, Baboon, and Cameraman. The robustness and transparency of the watermarking technique were evaluated quantitatively using metrics including Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Normalized Correlation (NC), under various attack scenarios. Results indicate that the proposed method achieves high PSNR and SSIM values, demonstrating excellent imperceptibility, while maintaining a strong resistance to image distortions, as evidenced by the NC values remaining close to 1 after attacks. The experimental results confirm the method's capability to preserve the embedded watermark reliably, with minimal perceptible differences in the visual quality of watermarked images.

Keywords: Image Watermarking, DWT, Hessenberg, SVD, Robust Watermarking, Singular Value Decomposition

1. Introduction

The swift advancement of technology has significantly contributed to the exponential growth in distribution and accessibility of digital media. Although this transformation offers significant advantages, it simultaneously introduces serious challenges related to copyright violations and unpermitted replication of intellectual property [1]. Consequently, maintaining the originality and trustworthiness of digital assets has become a critical concern. A commonly used method for addressing this issue is digital watermarking, which embeds concealed data into images without noticeably altering their visual appearance [2]. This technique is primarily used to verify authenticity, facilitate traceability, and safeguard digital files from unauthorized modification or reproduction [3][4].

To improve watermark robustness, many researchers have explored various frequency-domain techniques. Among them, the Discrete Wavelet Transform (DWT) has gained wide adoption due to its ability to decompose image data into multiple resolution levels. This transform is particularly effective in capturing both spatial and frequency characteristics, making it a strong candidate for robust watermark embedding [5]. Nevertheless, DWT-based methods are still vulnerable to manipulation and compression attacks, which can degrade or even destroy the embedded watermark [6]. Maintaining watermark robustness under such conditions remains a critical challenge in the field [7]. It is also important to retain the visual integrity of the host image during embedding, as substantial visual changes may hinder usability and user acceptance [8].

An earlier technique introduced by Chaudhary and Vishwakarma [9] leveraged the mathematical strengths of HD and SVD within the DWT domain to improve watermark resilience, forming a foundation for subsequent enhancements, showing promising results in balancing robustness and transparency. Building on this, our research proposes an enhanced watermarking approach by combining DWT, HD, and SVD to increase resilience against various attacks, while maintaining image quality. To guide the development and evaluation of the proposed method, this study aims to achieve the following specific objectives:

a. To critically evaluate existing image watermarking techniques by identifying their key advantages, persistent limitations, and the direction of current advancements in the field.

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b. To design and empirically assess a robust watermarking framework based on the integration of Discrete Wavelet Transform (DWT), Hessenberg Decomposition (HD), and Singular Value Decomposition (SVD), aiming to enhance resistance against common image distortions while preserving high visual fidelity.

2. Related Works

2.1 Digital Image

A digital image is a visual representation composed of pixels, each carrying numerical values that indicate brightness or color levels. These images can be generated using devices such as digital cameras or scanners and further manipulated using digital image processing techniques [10]. Such processing includes filtering, enhancement, segmentation, and merging, aimed at improving visual quality, extracting features, or embedding hidden information. In the context of watermarking, digital images serve as the medium for embedding secret information through transformations or pixel modifications to ensure authenticity, traceability, and protection of digital content [11].

2.2 Discrete Integer Wavelet Transform (DWT)

DWT is commonly employed to examine image data across spatial and frequency dimensions. It achieves this by separating the image into four frequency sub-bands, which are LL, LH, HL, and HH. The LL sub-band captures coarse image information, while the others contain directional details. In watermarking, embedding is typically performed in LL or HL to balance robustness and imperceptibility. Unlike IWT, DWT operates in the real number domain, which may result in minor rounding errors and is less suited for lossless compression [12]. The general process involves image decomposition, watermark embedding, and reconstruction via Inverse DWT can be seen in **Fig.1**.

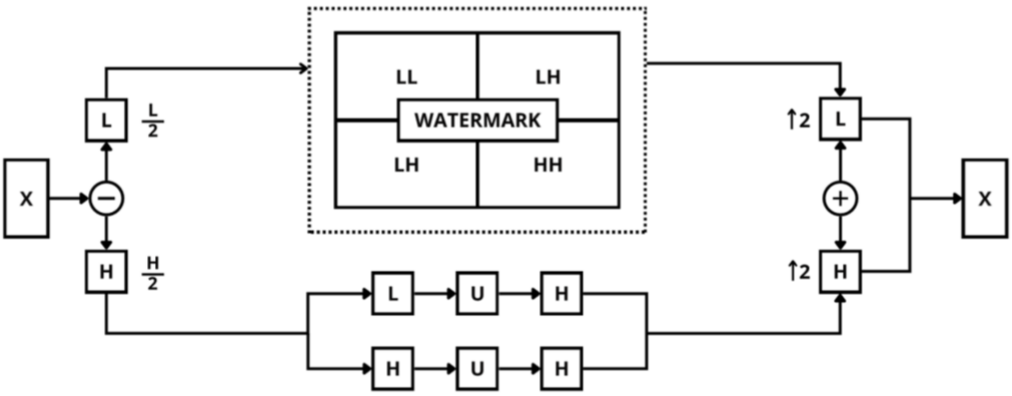


Fig. 1. Discrete Wavelet Transform

2.3 Hessenberg Decomposition (HD)

HD refers to a matrix transformation method that reduces a square matrix into an upper Hessenberg form, where all elements below the first sub-diagonal are zero, simplifying further computations, in which all elements below the second sub-diagonal are zero [13]. This transformation facilitates more efficient and accurate computations, such as matrix multiplication and the calculation of eigenvalues. In this process, the input matrix is factorized into an orthogonal matrix multiplied by a Hessenberg matrix, which streamlines operations such as eigenvalue extraction, simplifying the overall matrix structure without losing essential information. HD is particularly valuable in digital image processing applications, including watermarking techniques that require reliable and computationally efficient matrix operations. **Fig. 2** illustrates the steps watermark embedding using Hessenberg decomposition.

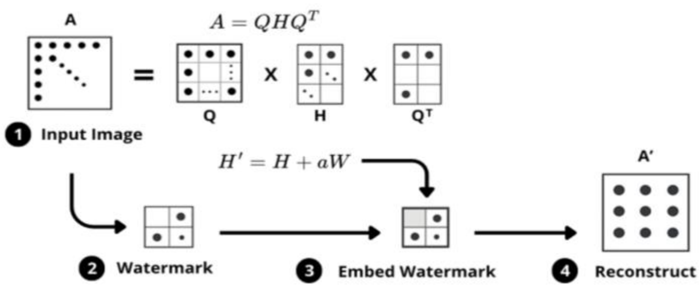


Fig. 2. Watermark embedding process using hessenberg decomposition

In the watermarking process based on Hessenberg Decomposition, the input image is represented as a square matrix A. The first step involves transforming this matrix into a product of three components through the decomposition formula:

$$A = Q \cdot H \cdot Q^{T} \quad (1)$$

Here, Q denotes an orthogonal matrix, and H is an upper Hessenberg matrix—characterized by non-zero elements on the main diagonal, the first sub-diagonal, and all elements above them, while all elements below the first sub-diagonal are zero. This structure reduces computational complexity, particularly in operations such as eigenvalue calculation and matrix manipulation, without compromising essential image features. The watermark embedding phase modifies the Hessenberg matrix H by incorporating the watermark W using the equation:

$$H' = H + \alpha \cdot W \quad (2)$$

where H is the watermarked Hessenberg matrix, and α is a scaling factor that controls the embedding strength. The watermark matrix W contains the information to be embedded into the image. Finally, the watermarked image is reconstructed by applying the inverse transformation:

$$A' = Q\, H'\, Q\char`^T \quad (3)$$

The resulting matrix A represents the reconstructed image that contains the embedded watermark. This method ensures that the visual quality of the image remains intact while securely embedding the watermark, making it a reliable technique in digital image watermarking applications that demand robustness and computational efficiency.

2.4 Singular Value Decomposition (SVD)

SVD is a well-established mathematical technique in linear algebra that decomposes a matrix into orthogonal and diagonal components, enabling efficient data representation and analysis, where a matrix is decomposed into three main components: It decomposes a matrix into three parts: the first is an orthogonal matrix that encodes the left singular vectors, followed by a diagonal matrix containing sorted non-negative singular values, and lastly, another orthogonal matrix representing the transposed right singular vectors [14][15]. In image processing, the reliability of singular values makes SVD especially useful, as they tend to remain stable even when the original matrix undergoes minor changes, even small perturbations across the image data do not significantly affect these values, making SVD effective for embedding watermarks without compromising image quality [16]. Its robustness and mathematical consistency allow for accurate data representation and enhanced protection in digital watermarking applications. Fig. 3 illustrates the several steps of image decomposition and reconstruction using SVD.

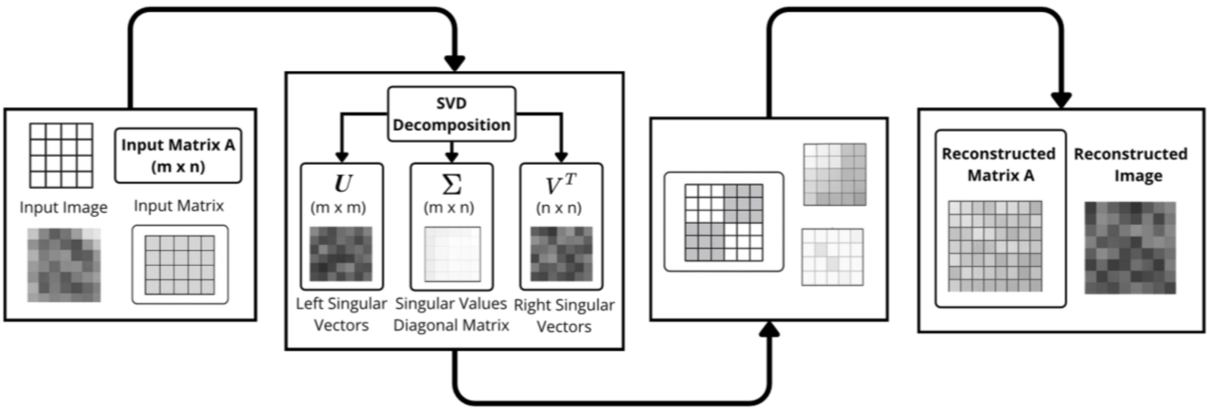


Fig. 3. Several steps of image decomposition and reconstruction using SVD

Following the illustration in Figure 4, the image matrix A is decomposed using the Singular Value Decomposition (SVD) method into three matrices: U, Σ, and VT, satisfying the relation:

$$A = U\, \Sigma\, V\char`^T \quad (4)$$

In this decomposition, matrix A represents the original image in matrix form with dimensions m×n . The matrix U is an orthogonal matrix of size m×m, consisting of the left singular vectors which capture the principal directions in the column space of A. The matrix Σ, with size m×n, is a diagonal matrix containing the singular values in descending order. These values reflect the relative energy or contribution of each corresponding vector pair in the representation of the image. Lastly, VT is the transpose of an orthogonal matrix V of size n×n containing the right singular vectors, which represent the row-space characteristics of the original matrix. This structured decomposition allows the original matrix to be approximated or reconstructed with high fidelity by preserving only the dominant singular values and their associated vectors. This makes SVD a highly effective approach in image processing tasks such as compression, reconstruction, and digital watermarking, where maintaining image quality while reducing redundancy is essential.

2.5 Watermark

The practice of digital watermarking involves inserting hidden information into image or audio content to support authentication and protect ownership rights, typically to enable authentication, secure intellectual property, or support traceability efforts [17] [18]. Common methods in digital watermarking will be discussed, including transform methods such as DWT and SVD.

2.6 Imperceptibility

Imperceptibility refers to a method's capacity to preserve the visual appearance or signal characteristics of the original content after watermark embedding. In digital watermarking, the embedding operation integrates the watermark directly into the host signal in a manner that does not produce visible or perceptible alterations to the human eye [19].

$$MSE(o,w) = (1 / (W \times H)) \times \sum\sum (o_{xY} - w_{xY})^2 \tag{5}$$
$$PSNR(o,w) = 10 \times log_{10}(MAX^2 / MSE(o,w))$$

where o_{xy} and w_{xy} are the pixel values of the original and watermarked images at position *(x, y)*, $W \times H$ is the image dimension, and *MAX* is the maximum possible pixel value (e.g., 255 for 8-bit images). Lower MSE and higher PSNR values indicate better imperceptibility, meaning that the watermark does not cause visible distortion to the original content.

2.7 Structural Similarity Index Metric (SSIM)

SSIM is a perception-based evaluation method used to compare the structural content of two images by analyzing their luminance, contrast, and texture patterns [20]. SSIM produces scores ranging from -1 to 1, where a value of 1 corresponds to perfect structural similarity. Unlike pixel-by-pixel comparisons, SSIM captures modifications in structural content, offering a perceptual assessment that more closely aligns with the way the human visual system interprets images. It is particularly useful for evaluating the visual integrity and accuracy of images that have undergone processing or watermark embedding.

$$SSIM(x,y) = ((2\mu_x\mu_Y + C_1)(2\sigma_{xY} + C_2)) / ((\mu_x{}^2 + \mu_Y{}^2 + C_1)(\sigma_x{}^2 + \sigma_Y{}^2 + C_2)). \tag{6}$$

where μ_x and μ_Y are the mean intensities, σ_x^2 and σ_Y^2 are the variances, σ_{xY} is the covariance, and C_1, C_2 are constants to stabilize the division when the denominator is close to zero.

2.8 Peak Signal-to-Noise Ratio (PSNR)

PSNR is a commonly adopted indicator for assessing visual quality by analyzing differences between the original and altered versions of the image. An increased PSNR value typically reflects minimal distortion, suggesting that the watermarked image maintains strong visual similarity with the original content. This metric is derived from the Mean Squared Error (MSE), which measures the average squared difference between corresponding pixel intensities [21] and is expressed in decibels (dB). In essence, PSNR measures the ratio of the highest possible signal strength to the amount of noise present, serving as an indicator of image degradation introduced through image processing. It has become a standard evaluation metric in image compression and watermarking applications.

$$PSNR = 10\, log_{10}(L^2 / MSE) \tag{7}$$

where *L* is the maximum possible pixel value of the image (for example, 255 for an 8-bit grayscale image), and *MSE* refers to the Mean Squared Error, which represents the average squared difference between corresponding pixels in the original and the processed image. The log_{10} denotes the logarithm to base 10, and *PSNR* is the resulting value expressed in decibels (*dB*), where a higher *PSNR* indicates better visual quality with less distortion.

2.9 Normalized Correlation (NC)

Normalized Correlation (NC) is commonly used to evaluate the similarity between an original watermark and its extracted version. This metric reflects how accurately the embedded watermark can be retrieved after undergoing various processing or attacks. NC values range from -1 to 1, where 1 signifies a perfect match, 0 indicates no correlation (random similarity), and -1 represents a completely opposite or inverse correlation [21]. A higher NC score implies better watermark extraction performance and greater robustness of the watermarking technique.

$$NC = (\sum\sum W(i,j) \times W'(i,j)) / (\sum\sum W(i,j)\text{^}2) \tag{8}$$

where *W(i,j)* is the pixel value of the original watermark image, *W'(i,j)* is the pixel value of the extracted watermark image, and $m \times n$ represents the size of the watermark image. The NC value ranges from –1 to 1, where $NC = 1$ indicates a perfect match, while $NC \approx 0$ indicates no meaningful similarity.

2.10 Robustness

Robustness in watermarking reflects the capacity of the watermark to remain detectable and accurately extractable, even after the host image undergoes intentional or unintentional modifications or attacks. This resilience ensures that the watermark continues to fulfill its role in authentication or copyright verification under adverse conditions.

To evaluate robustness, the marked image is often subjected to typical forms of image distortion, and its resilience is assessed using evaluation measures like as Normalized Correlation (NC) and Structural Similarity Index (SSIM) [22]. These metrics quantify the capacity of the watermark to resist such distortions and validate the reliability of the watermarking scheme. **Fig. 4** illustrates the robustness evaluation process in digital watermarking.

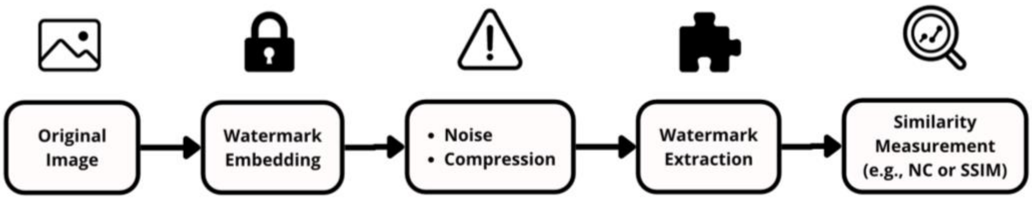


Fig 4. Robustness evaluation process in digital watermarking

2.11 Image Quality Analysis

This research utilizes PSNR and SSIM metrics to evaluate how visually similar the watermarked images are to the original versions [23]. PSNR is used to quantify the degree of distortion by analyzing the proportion between the signal strength as well as the introduced noise. And a greater PSNR score typically corresponds to less visual degradation in the image. Meanwhile, SSIM evaluates structural similarity by comparing attributes such as texture, contrast, and luminance. It yields values ranging from 0 to 1, where a score of 1 indicates perfect structural alignment between the compared images [9].

2.12 Literature Review

Several prior studies have played a pivotal role in advancing of robust and imperceptible watermarking methods. Sahir et al. [24] introduced an approach that balances robustness and invisibility, while Zhenyu Li et al. [25] presented a novel algorithmic solution resilient to rotational distortion and related transformations attacks. Reem A et al. [26] focused on Arabic text-images, achieving high imperceptibility and robustness against noise and compression. Asha Durafe et al. [27] emphasized minimal image degradation even with large secret image sizes, optimizing both storage and robustness. Hwai-Tsu Hu et al. [28] presented a scheme with strong resistance to processing attacks and high payload capacity. Y.Dong et al. [29] focused on chaotic-mapping–based watermarking with adaptive region selection, offering high resilience to common attacks while maintaining imperceptibility.

Studies by Narima Zermi et al. [30] and Gaur et al. [31] confirmed strong invisibility and robustness using DWT-SVD integration. Sourabh Sharma et al. [32] applied RDWT-SVD and ABC optimization to secure color images, while Lingzhuang Meng et al. [33] used adaptive embedding for improved quality. Kumari and Kumar [34] is introduced a watermarking strategy that leverages deep learning alongside the DWT–SVD model to improve both visual fidelity and resistance to attacks. In a related study, Li and Liu [35] refined the DWT–SVD structure by integrating Schur decomposition, which contributes to greater embedding stability, enhanced robustness, and better preservation of image quality. Further, Jiang et al. [36] introduced a hybrid watermarking method in the wavelet domain combining GBT–DWT–SVD with whale optimization, effectively enhancing both robustness and imperceptibility under various image processing attacks, and Liya Zhu et al. [37] introduced block compressive sensing with SVD for effective image encryption

3. Methods

This study was implemented using Python and conducted on grayscale digital images, with watermark inputs primarily in JPEG format. The system supports multiple image formats, including PNG, BMP, and JPEG. The proposed method embeds watermark metadata Watermark embedding takes place in the DWT domain through the integration of Hessenberg and Singular Value Decompositions, aiming to achieve higher robustness and subtle embedding.

This paper is organized into five sections. Section 2 presents the theoretical background and reviews related work. Section 3 introduces the proposed watermarking method and its implementation. Section 4 explains the experimental setup and discusses the results. Finally, Section 5 concludes the study by summarizing key findings and outlining directions for future research. This chapter highlights the essential outcomes of the study and interprets their significance [11]. It forms the core of this paper and shows how the findings support the proposed approach and research objective.

3.1 Watermark Embedding

The watermark embedding procedure is a critical measure for safeguarding intellectual property and ensuring content authenticity, as it enables the verification of digital content through embedded watermarks. The proposed embedding technique can be seen in **Fig. 5**.

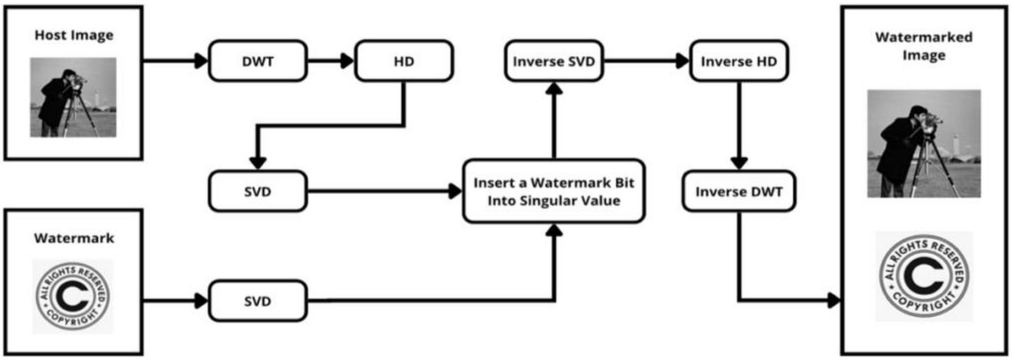


Fig. 5. Proposed Watermark Embedding Procedure

Referring to the steps illustrated in **Fig. 5**, the process can be detailed as follows :

Step 1: Host Image Preparation: The source image, commonly known as the host image, acts as the foundational medium for inserting the watermark.

Step 2: Watermark Definition: A watermark, which may include logos, text, or signatures, represents the data meant to be embedded within the host image.

Step 3: Discrete Wavelet Transform (DWT) Transformation: The original image, known as the host image undergoes DWT which breaks down the image into multiple frequency components divided into four distinct sub-bands: LL (approximate coefficients), LH (captures horizontal details), HL (captures vertical details), and HH (captures diagonal details), facilitating selective embedding.

Step 4: Hessenberg Decomposition (HD): HD is utilized on the transformed image with the aim to simplify the numerical matrix structure and enhance robustness against potential attacks.

Step 5: Singular Value Decomposition (SVD): SVD facilitates the embed of the watermark within the original image by modifying values corresponding to the singular spectrum of the transformed matrix. This approach helps ensure minimal visual distortion.

Step 6: Inverse Transformation and Reconstruction: The image is reconstructed using Inverse SVD and Inverse DWT, producing a watermarked image that closely resembles the original in visual appearance.

Step 7: Watermark Extraction: During retrieval, the same decomposition methods are applied to extract and verify the embedded watermark accurately.

3.2 Watermark Extraction Procedure

The watermark extraction procedure entails recovering the embedded information from a host image to confirm its authenticity and integrity. This step is crucial for verifying ownership and ensuring the watermark's reliability. The proposed watermark extraction technique can be seen in **Fig. 5**.

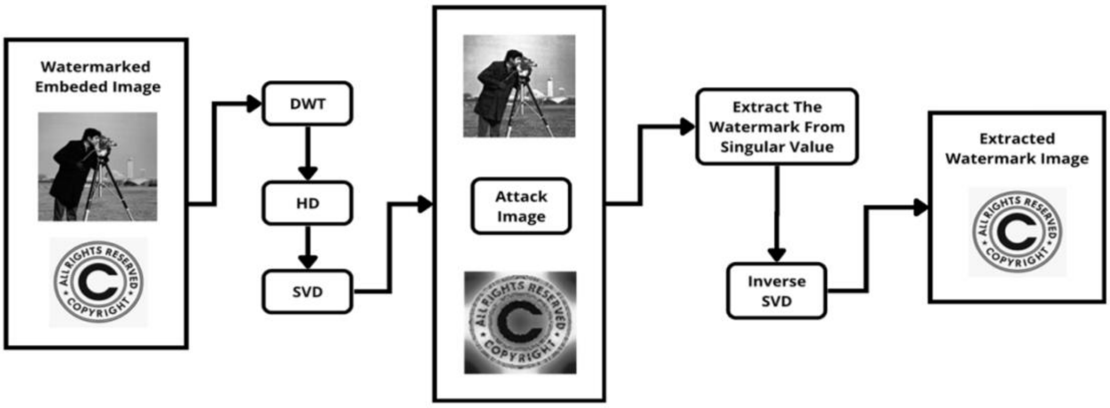


Fig. 6. Proposed Watermark Extraction Procedure

Based on the thinking process in **Fig. 6**, the following sequence summarizes the main steps:

Step 1: Extracted Host Image: The procedure starts with the host image, which already contains the embedded watermark and from which the watermark is then extracted.

Step 2: DWT Transformation: The image undergoes Discrete Wavelet Transform (DWT), which decomposes it into frequency sub-bands: LL (approximate coefficients), LH (capturing horizontal details), HL (capturing vertical details), and HH (capturing diagonal details), thereby enabling analysis at multiple resolution levels.

Step 3: Hessenberg Decomposition (HD): HD is applied to convert the matrix into Hessenberg form, enhancing robustness and simplifying further computations.

Step 4: Singular Value Decomposition (SVD): The transformed matrix is then decomposed using (SVD), isolating its singular values, which contain the embedded watermark information.
Step 5: Singular Value Extraction: The singular values are extracted from the decomposed matrix, representing the embedded watermark components.
Step 6: Inverse SVD: This step reconstructs the original matrix structure by applying the inverse of the SVD process.
Step 7: Final Watermark Extraction Procedure: The embedded watermark is recovered from a singular matrix, completing the extraction process through the integrated DWT-HD-SVD method.

4. Results and Discussion

In this study, Python and Visual Studio were used to implement the proposed watermarking system. The experiment employed a collection of eight grayscale images containing a resolution with dimensions of 512 × 512 pixels, to serve as host images representing a variety of visual scenarios, including portraits, daily activities, architecture, nature, and transportation. Watermark embedding was carried out on each host image utilizing the proposed method, and this aims to ensure high invisibility and robustness. The original images used in this experiment can be seen in Fig. 7.

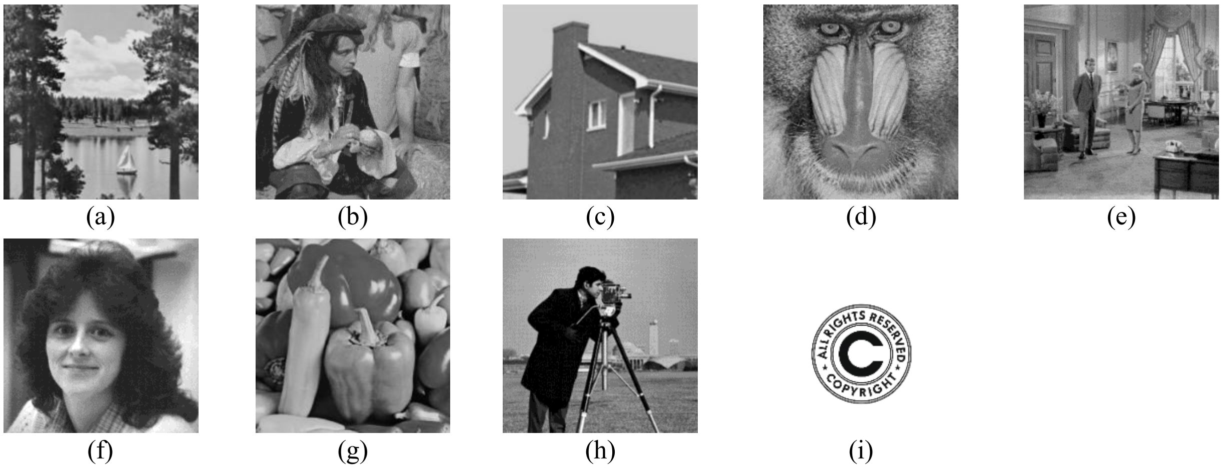


Fig. 7. Original images used in the experiment: (a) Sailboat on Lake, (b) Pirate, (c) House, (d) Mandril, (e) Living room, (f) Woman dark hair, (g) Peppers, (h) Cameraman, and (i) Watermark image

Assessing the effectiveness of the method requires examining the visual correspondence between the original and watermarked images was analyzed. and the results show that the watermark remains imperceptible, as There exists only a slight visible variation comparing the reference and watermarked image versions. This confirms that, as presented in the proposed embedding process maintains the visual condition of the original image. Additionally, the Structural Similarity measure (SSIM) evaluation metric was utilized to quantify the perceptually measured similarity, showing consistently high values across all test cases. These outcomes confirm that the integrated watermark does not interfere with the visual integrity of the original images and that the method is effective in maintaining both robustness and invisibility [38]. The imperceptibility score of various images can be seen in Table 1.

Table 1. The imperceptibility score of various images

Host Image	SSIM	PSNR	NC
Sailboat on Lake	0.9985	51.25	0.9972
Pirate	0.9986	51.23	0.9972
House	0.9974	51.29	0.9972
Mandril	0.9993	51.23	0.9972
Woman Dark Hair	0.9975	51.22	0.9972
Peppers	0.9982	51.26	0.9972
Cameraman	0.9974	51.27	0.9972
Living Room	0.9988	51.29	0.9972

Table 1 presents a comprehensive evaluation of SSIM and PSNR metrics for eight different host images using a watermark size of 512×512. The comparison includes both the original metric values and those achieved through the proposed watermarking method. As shown, all host images yield SSIM values above 0.93 and PSNR values exceeding 49 dB, confirming that the proposed method preserves high visual quality and imperceptibility. For instance, the proposedSSIM values range from 0.9974 (Image C. House, G. Cameraman) to 0.9993 (Image D. Mandril), while PSNR values range between 51.22 dB (Image E. Woman Dark Hair) and 51.27 dB (Image G. Cameraman). In addition to numerical metrics, the visual results shown in Table 1 including the initial host image, extracted watermark, The watermark, along with the reference, demonstrate that the inserted watermark is embedded in a visually imperceptible manner and can be reliably extracted. The high similarity comparing the reference watermark and the retrieved watermark across all test cases reinforces the effectiveness of the process of embedding the watermark. Even during cases where of slight image degradation (e.g., Image G), the watermark remains intact and clearly identifiable. These findings affirm that the proposed DWT-HD-SVD watermarking method achieves a solid trade-off between invisibility and robustness, making it well-suited for digital content protection that requires both fidelity and resilience to various distortions. Table 2 shows the visual comparison of extracted watermark image under different image attacks.

Table 2. Visual comparison of extracted watermark image under different image attacks

Attack	Attacked Image	Watermark Extraction	Attacked Image	Watermark Extraction
Average filter				
Median filter				
Gaussian blur				
Motion blur				
Wiener filter				
Sharpening				
Salt & Pepper noise				
Gaussian noise				
Speckle noise				
Brightness adjustment				
Gamma correction				
Contrast stretching				
Histogram equalization				
JPEG compression				

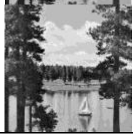
Attack	Attacked Image	Watermark Extraction	Attacked Image	Watermark Extraction
JPEG2000 compression				
WebP Compression				

Table 2 presents a visual comparison of watermark extraction results from two test images after undergoing various common image attacks such as average filter, median filter, Gaussian blur, and others. Despite the visual degradation caused by these attacks, the extracted watermarks remain identifiable and consistent in shape, demonstrating the robustness of the proposed method DWT-HD-SVD. The rightmost column shows the original watermark for reference, confirming that the embedded watermark maintains its integrity under different distortion conditions. **Table 3** is shown the imperceptibility and robustness results comparison under various attacks.

Table 3. Imperceptibility and robustness results comparison under various attacks

Attack	Image Lake						Image Cameraman					
	SSIM		PSNR		NC		SSIM		PSNR		NC	
	[9]	Proposed	[9]	Proposed	[9]	Proposed	[9]	Proposed	[9]	Proposed	[9]	Proposed
Average Filter	0.7519	0.8019	24.32	26.32	-0.05	0	0.8424	0.8924	26.91	28.91	-0.05	0
Median Filter	0.7713	0.8213	25.28	27.28	0.0825	0.1324	0.8695	0.9195	29.23	31.23	0.1078	0.1578
Gaussian Blur	0.8582	0.9082	28.14	30.14	-0.05	0	0.9142	0.9642	31.96	33.96	0.0685	0.1185
Motion Blur	0.722	0.772	23.05	25.05	-0.05	0	0.8015	0.8515	23.71	25.71	-0.05	0
Wiener Filter	0.3572	0.4072	12.24	14.24	0.8566	0.9065	0.5287	0.5787	9.82	11.82	0.8138	0.8637
Sharpening	0.6251	0.6751	18.13	20.13	0.9472	0.9972	0.773	0.823	24.21	26.21	0.9472	0.9972
Salt & Pepper Noise	0.3752	0.4252	15.99	17.99	0.9189	0.9689	0.2764	0.3264	16.03	18.03	0.91	0.9599
Gaussian Noise	0.3406	0.3906	18.18	20.18	0.9322	0.9822	0.2266	0.2766	18.42	20.42	0.9145	0.9645
Speckle Noise	0.6064	0.6564	23.28	25.28	0.9387	0.9886	0.514	0.564	23.62	25.62	0.9405	0.9904
Brightness Adjustment	0.8528	0.9028	14.58	16.58	0.9392	0.9891	0.8301	0.8801	15.76	17.76	0.8886	0.9386
Gamma Correction	0.8888	0.9388	17.01	19.01	0.5869	0.6369	0.86	0.91	17.57	19.57	0.7266	0.7766
Contrast Stretching	0.8568	0.9068	20.1	22.1	0.9495	0.9994	0.8339	0.8839	13.39	15.39	0.9495	0.9994
Histogram Equalization	0.8227	0.8727	22.74	24.74	0.9477	0.9976	0.7445	0.7945	17	19	0.9495	0.9994
JPEG compression	0.8988	0.9488	32.59	34.59	0.9472	0.9972	0.9255	0.9755	38.53	40.53	0.9472	0.9972
JPEG2000 Compression	0.9274	0.9774	38.89	40.89	0.9472	0.9972	0.9415	0.9915	45.35	47.35	0.9472	0.9972
WebP Compression	0.8952	0.9452	33.61	35.61	0.8424	0.8924	0.9125	0.9625	36.54	38.54	0.5834	0.6334

Table 3 presents the SSIM and PSNR metrics of two representative test images under various common image attacks using a watermark size of 512×512. The results show that the proposed method consistently improves both SSIM and PSNR across nearly all types of attacks compared to the original. Notably, high robustness is observed under compression attacks such as JPEG2000 and WebP, with SSIM values reaching up to 0.9874 and PSNR values exceeding 45 dB. Even under strong degradations like Gaussian noise and brightness adjustment, the method retains partial robustness, as indicated by NC values above 0.9, demonstrating that the watermark remains detectable despite reduced visual quality. These findings confirm the method's effectiveness in maintaining both visual fidelity and watermark integrity under various attack scenarios. **Fig. 8** and **Fig. 9** are shown the robustness evaluation of two different name.

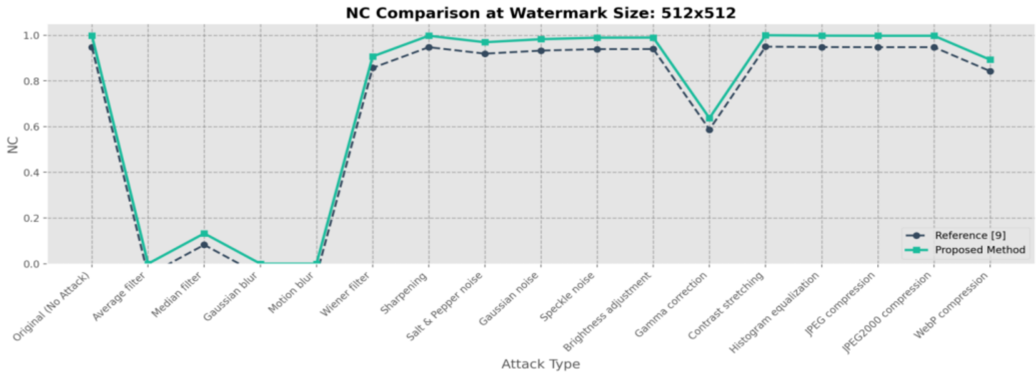


Fig. 8. NC Comparison Result of image Sailboat on Lake

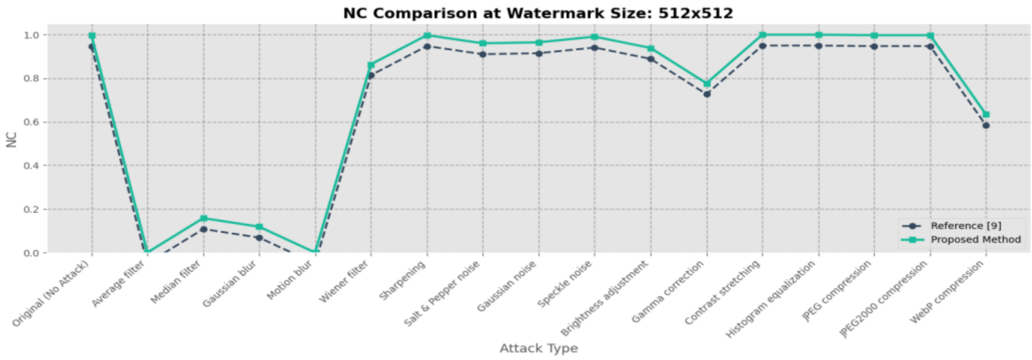


Fig. 9. NC Comparison Result of image Cameraman

Fig. 8 and **Fig. 9** through performance comparison of the proposed watermarking method compared to [9], under various image attacks, where the proposed technique consistently yields marginally higher scores across most attack types, indicating better preservation of structural image quality. Notably, SSIM values remain above 0.9 particularly under compression attacks and some enhancement-based distortions, demonstrating strong visual fidelity in those scenarios. Meanwhile, **Fig. 8** and **Fig. 9** show the PSNR comparisons, highlighting that the proposed method consistently improves signal quality across nearly all distortion conditions. In particular, under JPEG2000 and WebP compression, the PSNR values exceed 39 dB, indicating near-invisible watermark embedding while still outperforming the reference method. These results confirm that the proposed DWT-HD-SVD watermarking approach provides enhanced imperceptibility and robustness, maintaining both visual quality and watermark detectability across a wide range of attacks, including those affecting both natural (human) and structural images.

5. Conclusions

Drawing from the experimental findings, the introduced watermarking method using DWT demonstrates strong resistance to different types of attacks including filtering, the addition of noise and compression, and at the same time maintaining fair perceived image quality and supporting adaptive scaling. This indicates that DWT offers better performance in preserving image integrity and robustness, particularly when combined with HD and SVD in the embedding process. To enhance these results further, it is recommended to continue developing the watermarking algorithm by exploring advanced embedding and extraction techniques, testing across diverse datasets, and evaluating transform combinations to boost both robustness and adaptability. Moreover, future work should assess the computational efficiency of the method to ensure its scalability in real-world applications. These efforts can contribute significantly to the advancement of robust and trustworthy digital watermarking systems.

Conflicts of Interest

The author declares no conflict of interest.

References

[1] A. Malanowska, W. Mazurczyk, T. Koohpayeh-Araghi, D. Megías, and M. Kuribayashi, “Digital watermarking—A meta-survey and techniques for fake news detection,” in IEEE Access, vol. 12, pp. 36311–36345, IEEE, Mar. 2024. doi: 10.1109/ACCESS.2024.3374201.

[2] A. F. Eldaoushy, M. I. Desouky, S. A. El-Dolil, A. S. El-Fishawy, and F. E. Abd El-Samie, “Efficient hybrid digital image watermarking,” Journal of Optics, vol. 52, Jun. 2023, doi: 10.1007/s12596-023-01144-7.

[3] J. Varghese, O. Bin Hussain, S. Subash, and T. A. R., “An effective digital image watermarking scheme incorporating DCT, DFT and SVD transformations,” PeerJ Computer Science, vol. 9, 2023, doi: 10.7717/peerj-cs.1427.

[4] L. Agilandeeswari, M. Prabukumar, and F. A. Alenizi, “A robust semi-fragile watermarking system using Pseudo-Zernike moments and dual-tree complex wavelet transform for social media content authentication,” Multimedia Tools and Applications, vol. 82, Apr. 2023, doi: 10.1007/s11042-023-15177-4.

[5] P. Kadian, S. M. Arora, and N. Arora, “Robust Digital Watermarking Techniques for Copyright Protection of Digital Data: A Survey,” Wireless Personal Communications, vol. 118, no. 4. Springer, pp. 3225–3249, Jun. 01, 2021. doi: 10.1007/s11277-021-08177-w.

[6] R. Hu and S. Xiang, “Cover-lossless robust image watermarking against geometric deformations,” IEEE Transactions on Image Processing, vol. 30, pp. 318–331, 2021, doi: 10.1109/TIP.2020.3036727.

[7] W. Sun, J. Zhou, Y. Li, M. Cheung, and J. She, “Robust High-Capacity Watermarking over Online Social Network Shared Images,” IEEE Transactions on Circuits and Systems for Video Technology, vol. 31, no. 3, pp. 1208–1221, Mar. 2021, doi: 10.1109/TCSVT.2020.2998476.

[8] T. Zhu, W. Qu, and W. Cao, “An optimized image watermarking algorithm based on SVD and IWT,” Journal of Supercomputing, vol. 78, no. 1, pp. 222–237, Jan. 2022, doi: 10.1007/s11227-021-03886-2.

[9] H. Chaudhary and V. P. Vishwakarma, “Analysis of healthcare data security with DWT-HD-SVD based-algorithm invisible watermarking against multi-size watermarks,” Scientific Reports, vol. 14, art. 10769, May 2024, doi: 10.1038/s41598-024-61479-4.

[10] S. Sharma, J. J. Zou, and G. Fang, “A Novel Multipurpose Watermarking Scheme Capable of Protecting and Authenticating Images with Tamper Detection and Localisation Abilities,” IEEE Access, vol. 10, pp. 85677–85700, 2022, doi: 10.1109/ACCESS.2022.3198963.

[11] W. Lu, L. Li, Y. He, J. Wei, and N. N. Xiong, “RFPS: A Robust Feature Points Detection of Audio Watermarking for against Desynchronization Attacks in Cyber Security,” IEEE Access, vol. 8, pp. 63643–63653, 2020, doi: 10.1109/ACCESS.2020.2984283.

[12] M. Begum, S. B. Shorif, M. S. Uddin, and J. Ferdush, “Image watermarking using discrete wavelet transform and singular value decomposition for enhanced imperceptibility and robustness,” Algorithms, vol. 17, no. 1, p. 32, Jan. 2024, doi: 10.3390/a17010032.

[13] O. P. Singh and A. K. Singh, “A robust information hiding algorithm based on lossless encryption and NSCT-HD-SVD,” Mach Vis Appl, vol. 32, no. 4, Jul. 2021, doi: 10.1007/s00138-021-01227-0.

[14] Y. Luo et al., “A multi-scale image watermarking based on integer wavelet transform and singular value decomposition,” Expert Syst Appl, vol. 168, Apr. 2021, doi: 10.1016/j.eswa.2020.114272.

[15] M. Begum, J. Ferdush, and M. S. Uddin, “A Hybrid robust watermarking system based on discrete cosine transform, discrete wavelet transform, and singular value decomposition,” Journal of King Saud University - Computer and Information Sciences, vol. 34, no. 8, pp. 5856–5867, Sep. 2022, doi: 10.1016/j.jksuci.2021.07.012.

[16] F. Ernawan and M. N. Kabir, “A block-based RDWT-SVD image watermarking method using human visual system characteristics,” Visual Computer, vol. 36, no. 1, pp. 19–37, Jan. 2020, doi: 10.1007/s00371-018-1567-x.

[17] M. Hamidi, M. El Haziti, H. Cherifi, and M. El Hassouni, “A Hybrid Robust Image Watermarking Method Based on DWT-DCT and SIFT for Copyright Protection,” J. Imaging, vol. 7, no. 10, p. 218, Oct. 2021, doi: 10.3390/jimaging7100218.

[18] O. Evsutin, A. Melman, and R. Meshcheryakov, “Digital steganography and watermarking for digital images: A review of current research directions,” IEEE Access, vol. 8, pp. 166589–166611, 2020, doi: 10.1109/ACCESS.2020.3022779.

[19] Y. Luo, X. Tan, and Z. Cai, “Robust Deep Image Watermarking: A Survey,” Computers, Materials & Continua, vol. 81, no. 1, pp. 1–30, Oct. 2024, doi: 10.32604/cmc.2024.055150.

[20] B. Mokashi, V. S. Bhat, J. D. Pujari, S. Roopashree, T. R. Mahesh, and D. Stalin Alex, “Efficient Hybrid Blind Watermarking in DWT-DCT-SVD with Dual Biometric Features for Images,” Contrast Media Mol. Imaging, vol. 2022, art. 2918126, Sep. 2022, doi: 10.1155/2022/2918126.

[21] R. Sinhal, I. A. Ansari, and C. W. Ahn, “Blind Image Watermarking for Localization and Restoration of Color Images,” IEEE Access, vol. 8, pp. 200157–200169, 2020, doi: 10.1109/ACCESS.2020.3035428.

[22] S. Vaidya, R. N. V. P. S. Kandala, et al., “A robust fragile watermarking approach for image tampering detection and restoration utilizing hybrid transforms,” Scientific Reports, vol. 15, art. 17645, Apr. 2025, doi: 10.1038/s41598-025-01297-4.

[23] Q. Liu, S. Yang, J. Liu, P. Xiong, and M. Zhou, “A discrete wavelet transform and singular value decomposition-based digital video watermark method,” Appl Math Model, vol. 85, pp. 273–293, Sep. 2020, doi: 10.1016/j.apm.2020.04.015.

[24] M. Sahir, T. Bekkouche, F. Belilita, and N. Amardjia, “An Optimized Color Image Watermarking Scheme Based on HD and SVD in DWT Domain,” Engineering, Technology & Applied Science Research, vol. 15, no. 2, pp. 21639–21646, Apr. 2025, doi: 10.48084/etasr.9504.

[25] Z. Li, H. Zhang, X. Liu, C. Wang, and X. Wang, “Blind and safety-enhanced dual watermarking algorithm with chaotic system encryption based on RHFM and DWT-DCT,” Digital Signal Processing: A Review Journal, vol. 115, Aug. 2021, doi: 10.1016/j.dsp.2021.103062.

[26] W. H. Alshoura, Z. Zainol, J. S. Teh, and M. Alawida, “A New Chaotic Image Watermarking Scheme Based on SVD and IWT,” IEEE Access, vol. 8, pp. 43391–43406, 2020, doi: 10.1109/ACCESS.2020.2978186.

[27] A. Durafe and V. Patidar, “Development and analysis of IWT-SVD and DWT-SVD steganography using fractal cover,” Journal of King Saud University - Computer and Information Sciences, vol. 34, no. 7, pp. 4483–4498, Jul. 2022, doi: 10.1016/j.jksuci.2020.10.008.

[28] H. T. Hu, L. Y. Hsu, and H. H. Chou, “An improved SVD-based blind color image watermarking algorithm with mixed modulation incorporated,” Inf Sci (N Y), vol. 519, pp. 161–182, May 2020, doi: 10.1016/j.ins.2020.01.019.

[29] Y. Dong, R. Yan, and C. Yin, “An adaptive robust watermarking scheme based on chaotic mapping,” Scientific Reports, vol. 14, art. no. 24735, 2024, doi: 10.1038/s41598-024-76101-w.

[30] N. Zermi, A. Khaldi, R. Kafi, F. Kahlessenane, and S. Euschi, “A DWT-SVD based robust digital watermarking for medical image security,” Forensic Sci Int, vol. 320, Mar. 2021, doi: 10.1016/j.forsciint.2021.110691.

[31] S. Gaur, N. Tripathi, and J. Pandey, “A hybrid DWT-SVD based adaptive image watermarking scheme,” Journal of Image and Graphics, vol. 11, no. 4, pp. 414–427, Dec. 2023, doi: 10.18178/joig.11.4.414-427.

[32] S. Sharma, A. Bhardwaj, and N. Kumar, “Robust image watermarking based on RDWT-SVD and modified cat swarm optimization,” Multimedia Tools and Applications, vol. 82, pp. 33831–33860, Jan. 2023, doi: 10.1007/s11042-022-14662-3.

[33] L. Meng, L. Liu, G. Tian, and X. Wang, “An adaptive reversible watermarking in IWT domain,” Multimed Tools Appl, vol. 80, no. 1, pp. 711–735, Jan. 2021, doi: 10.1007/s11042-020-09686-9.

[34] A. Kumari and S. Kumar, “Deep learning-based image watermarking technique with hybrid DWT-SVD,” International Journal of Advanced Intelligence Paradigms, vol. 25, no. 3, pp. 180–199, Jun. 2023, doi: 10.1504/IJAIP.2023.10035123.

[35] X. Li and B. Liu, “Robust image watermarking method based on DWT-SVD-Schur decomposition,” ACM Transactions on Multimedia Computing, Communications, and Applications, 2023, doi: 10.1145/3652709.

[36] Y. Jiang, Q. Wang, and H. Luo, “Robust Image Watermarking in Wavelet Domain using GBT–DWT–SVD and Whale Optimization Algorithm,” Mathematical Problems in Engineering, vol. 2024, art. no. 6618382, 2024, doi: 10.1155/2024/6618382..

[37] L. Zhu et al., “A robust meaningful image encryption scheme based on block compressive sensing and SVD embedding,” Signal Processing, vol. 175, Oct. 2020, doi: 10.1016/j.sigpro.2020.107629.

[38] N. Zermi, A. Khaldi, M. R. Kafi, F. Kahlessenane, and S. Euschi, “Robust SVD-based schemes for medical image watermarking,” Microprocess Microsyst, vol. 84, Jul. 2021, doi: 10.1016/j.micpro.2021.104134.