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Enhancing quality measurement for visible and invisible watermarking based on M-SVD and DCT

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ABSTRACT

This study introduces an advanced method for evaluating non-blind watermarking quality, leveraging both visible and invisible watermarking techniques grounded in principles of discrete cosine transform (DCT) and modified singular value decomposition (M-SVD). The primary focus is to refine the assessment process of watermarked images by integrating M-SVD, known for its efficacy in measuring image quality and watermarking performance. Results from the M-SVD implementation exhibit a striking resemblance to the original images. The mean squared error (MSE) values for watermarked images range from 0.0003 to 0.0168, while peak signal-to-noise ratio (PSNR) values vary between 42.52 dB and 82.72 dB. These outcomes underscore the potential of DCT and M-SVD techniques in bolstering watermarking processes, especially in invisible watermarking contexts.

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1. INTRODUCTION

Image quality is a crucial aspect in the digital world, influencing the effectiveness and visual impression conveyed [1]-[4]. In an era of advancing technology, the threat to image integrity has escalated due to the ease of manipulating images using sophisticated editing tools. Moreover, as images are increasingly susceptible to unauthorized alterations, ensuring their integrity, and authenticity becomes paramount [5]-[7]. Digital watermarking allows for the insertion of imperceptible watermarks into images as unique identifiers or authentication proofs, safeguarding images against unauthorized modifications, and ensuring their authenticity [8]. In setting the context for this research, it is imperative to delineate the prevailing landscape and state-of-the-art advancements within the domain of digital watermarking and image integrity [9]. Over recent years, the proliferation of digital media and the advent of sophisticated image editing tools have engendered a heightened vulnerability to image tampering and unauthorized usage [10]. Consequently, the quest for robust, reliable, and imperceptible watermarking techniques has intensified, necessitating innovative methodologies that seamlessly integrate with existing image processing frameworks [11], [12]. The evolution of watermarking strategies has witnessed a paradigm shift towards invisible watermarking solutions, wherein the emphasis lies not only on embedding ownership or authentication data covertly but also on preserving the inherent quality and visual fidelity of the images [13]. Concurrently, advancements in quality measurement metrics have emerged as pivotal determinants, facilitating rigorous evaluation, and validation of watermarking techniques [14].

The utilization of digital watermarking becomes highly relevant in enhancing image quality and preserving its integrity in an era where visual information plays a central role across various sectors, ranging from security to copyright and identification purposes [15]. In addition to traditional digital watermarking, non-blind watermarking stands out as an advanced technique that offers distinct advantages in ensuring image integrity and security [8], [16]. Unmarked image during watermark extraction. This additional information allows for more sophisticated algorithms and larger data embedding capacities, leading to enhanced resistance against various attacks and better preservation of image quality [17], [18]. Non-blind based on visible and invisible watermarking is particularly beneficial in applications where secure storage or access to the original image is feasible, such as copyright protection, media forensics, and content authentication [18]. Non-blind based on visible and invisible watermarking provides a reliable and enduring method to protect the intellectual property and integrity of digital images in diverse domains [19]. As the digital landscape continues to evolve, non-blind watermarking serves as a potent defense mechanism to combat the growing threats of image manipulation and unauthorized use, reinforcing the importance of maintaining the authenticity and ownership of visual content.

The research objective of this study is to advance watermarking techniques by synergistically integrating the capabilities of the discrete cosine transform (DCT) and modified singular value decomposition (M-SVD) methodologies. The proposed approach aims to enhance both the embedding and evaluation aspects of watermarking. Specifically, the DCT technique is utilized to embed the watermark seamlessly into the host content while ensuring its imperceptibility. This integration not only maintains the visual quality of the media but also fortifies its resistance against various attacks. Moreover, the introduction of the M-SVD method augments the quality assessment metrics, thereby providing more comprehensive evaluation benchmarks. By combining these techniques, the research contributes to the advancement of watermarking methodologies, offering improved robustness and fidelity in watermark embedding and evaluation processes. The novelty lies in the integrated use of DCT and M-SVD, which collectively bolster the security and reliability of watermarking systems, thus addressing inherent challenges and advancing the state-of-the-art in digital watermarking research.

Based on the review, non-blind based on visible and invisible watermarking has demonstrated significant advantages in bolstering the security and robustness of embedded watermarks [15], [20]-[22]. This approach, which requires access to the original, unmarked image during watermark extraction, enables the use of advanced algorithms and larger data embedding capacities. Consequently, non-blind watermarking based on visible and invisible exhibits enhanced resistance against various attacks and better preservation of image quality compared to blind watermarking [23]. This makes it a valuable technique in applications where secure storage or access to the original image is feasible, such as copyright protection, media forensics, and content authentication [24], [25]. The research aims and gaps can be described as the following points:

a. Address the limitations of existing quality evaluation methods for non-blind watermarking techniques that fail to accurately assess the impact of embedded watermarks on image quality.
b. Improve the precision and reliability of quality measurement in non-blind based on visible and invisible watermarking by incorporating an M-SVD approach.
c. Develop an innovative framework that evaluates both the robustness and invisibility aspects of non-blind based on visible and invisible watermarking schemes.
d. Examine the watermark's resilience against prevalent image processing procedures and attacks utilizing the adapted SVD technique, offering valuable discernment into the comprehensive security and efficacy of non-blind watermarking methodologies.
e. Facilitate more reliable comparisons and benchmarking of different non-blind watermarking algorithms through clear and objective quality assessment criteria.

2. METHOD

2.1. Related research

Several pertinent studies in the realm of digital image watermarking have investigated diverse methodologies aimed at augmenting image security and copyright safeguarding. Among these, a significant strategy is exemplified by the blind watermarking technique, obviating the necessity for the source image during watermark retrieval. Research by Mohammed *et al*. [26] recalled that several blind watermarking techniques have been proposed, including the discrete wavelet transform (DWT) and singular value decomposition (SVD) methods. These techniques integrate the watermark within certain frequency components of the image to attain imperceptibility. In research by Elbasi [27], data hiding, watermarking, and steganography have emerged as significant research and application areas, particularly for copyright protection in digital images. Most studies in this field utilize frequency domain techniques for watermark embedding. Among these, wavelet algorithms stand out, with the use of a scaling factor in both embedding and extraction processes. The findings illustrated that algorithms based on adaptable scaling factors showcase exceptional performance concerning resilience, security, and data capacity. Research by Khanam *et al*. [28] also focuses on non-blind symmetric image watermarking techniques for ownership protection in multimedia data. In their study, they propose a method that employs DWT and DCT to embed watermarks into the host image. Authors utilize a secret key for watermark embedding and extraction, enhancing the system's security. Their approach achieves promising results with a PSNR ranging from 45.23 to 51.89 and an NC from 0.8561 to 0.9778. While this method demonstrates robustness against several attacks, it is noteworthy that the PSNR values and NC range are slightly lower compared to the proposed method in our paper. Research by Yasmeen and Uddin [29], introduces a hybrid watermarking scheme integrating DWT and SVD. This approach operates through multi-level operations of DWT and SVD for embedding and extracting features, enhancing the robustness of the watermark against various attacks. Through experimentation, the proposed method achieves a PSNR of 34.73 dB and a correlation coefficient of 0.9975 on Lena images, demonstrating its effectiveness in maintaining image quality and watermark integrity.

In this study, we introduce an enhanced method for the evaluation of quality in non-blind watermarking. This approach leverages both discernible and concealed watermarking methods rooted in M-SVD and DCT principles. The principal objective is to enhance the assessment procedure for watermarked images by integrating the M-SVD technique, which has d=emonstrated efficacy in gauging image quality and watermarking efficacyThrough the implementation of M-SVD, we aim to attain more precise and dependable outcomes concerning mean square error (MSE), peak signal to noise ratio (PSNR), universal quality index (UQI), mean of structural similarity index measurement (MSSIM), normalized correlation (NC), and normalized cross corelation (NCC) measurements. By incorporating the DCT technique into invisible watermarking, the intention is to diminish the watermarking intensity within the images. The application of M-SVD not only allows for the more adept discernment of nuanced distinctions between the original and embedded watermark image but also contributes to a more comprehensive appraisal of the watermarking process.

2.2. Discrete cosine transform

DCT is employed as a pivotal technique within the context of invisible watermarking, facilitating the seamless integration of imperceptible watermark information into host media by converting spatial domain data into frequency domain coefficients [30], [31]. In the context of invisible watermarking, the DCT facilitates the seamless integration of imperceptible watermark information into host media by transforming the original spatial domain representation into a frequency domain representation [30]. This conversion allows for the embedding of auxiliary data within the host media while minimizing perceptible alterations to the original content. Through its ability to represent signals in terms of frequency components, the DCT enables efficient and effective manipulation of digital content for purposes such as copyright protection, authentication, and content identification. Based on DCT equation can be seen in (1). Where X_n denotes the k^{th} DCT coefficient representing the transformed signal, x_n corresponds to the individual samples of the input signal, N signifies the total number of samples within the input signal, and k ranges from 0 to $N-1$, serving as the index for each DCT coefficient.

$$X_k = \sum_{n=0}^{N-1} x_n \times Cos\left(\frac{\pi}{N}\left(n+\frac{1}{2}\right)k\right) \tag{1}$$

2.3. Modified singular value decomposition

M-SVD is an innovative technique that extends the classical SVD algorithm to enhance its effectiveness in various applications [32]. In M-SVD, the original SVD process is modified to accommodate specific requirements or constraints, making it adaptable to diverse data types and problem domains. This adaptability allows M-SVD to effectively handle non-standard data structures, noise, missing values, and other complexities that may arise in real-world datasets. The versatility of M-SVD facilitates its implementation across a multitude of domains, encompassing but not limited to image manipulation, signal scrutiny, efficient data encoding, and cooperative filtering tasks [32], as shown in (2). Where D represents the midpoint of the sorted D_i and n represents a total number of pixels.

$$M-SVD = \frac{\sum_{i=1}(Image\ Size/n)^2\ |D_i - D_{mid}|}{(Image\ Size/n)^2} \tag{2}$$

2.4. Proposed scheme

The proposed method aims to enhance the quality measurement of non-blind based on visible and invisible watermarking techniques by introducing novel strategies for evaluating the impact of embedded watermarks on image quality. The proposed method also initiates with the selection of images, including Lena, Baboon, and Peppers, followed by the initialization of a watermark denoted as "Secret Message Watermark" with a size of 512×512×3. The embedding process entails several steps. Firstly, the watermarked and original images are preprocessed by mixing and scaling them to the range [0,1]. Subsequently, SVD is performed on both the watermarked and original images, resulting in matrices U_{wm}, S_{wm}, and V_{wm}, as well as $U_{original}$, $S_{original}$, and $V_{original}$, respectively. The singular values in S_{wm} are replaced with those from $S_{original}$, and the watermarked image is reconstructed with modified singular values. Finally, the performance evaluation is conducted by calculating the PSNR, UQI, and MMSIM between the reconstructed watermarked image and the original image. This process culminates in the acquisition of performance results for the proposed method. Based on Figure 1, the flow algorithm can be seen:

a. Input: $watermarked\_image$ (watermarked image), $original\_image$ (original image) ← $W_{in} \times H_{in} \times D_{in} \leftarrow 512 \times 512 \times 3$.
b. Preprocessing: mix the $watermarked\_image$ and $original\_image$ and then scale them to the range $[0, 1]$.
c. SVD: perform SVD on the $watermarked\_image$ to get matrices ← U_{wm}, S_{wm}, and V_{wm}. Perform SVD on the original_image to get matrices ← $U_{original}$, $S_{original}$, and $V_{original}$.
d. Modify singular values: replace the $singular\ values\ (diagonal\ elements\ of\ S_{wm})$ with the singular values from $S_{original}$.
e. Reconstruction: reconstruct the watermarked image with modified singular values: $watermarked_{image_{MSVD}} \leftarrow U_{wm} * S_{modified} * V_{wm'}$.
f. Performance evaluation: calculate PSNR between $watermarked\_image\_msvd$ and $original\_image$. Calculate UQI between $watermarked\_image\_msvd$ and $original\_image$. Calculate MMSIM between $watermarked\_image\_msvd$ and $original\_image$.
g. Output: $msvd\_result$ (a struct containing PSNR, UQI, and MMSIM).

Based on the proposed scheme in Figure 2, which illustrates the application of the DCT method, the utilization of DCT in processing facilitates the generation of images with invisible watermarks. Conversely, the absence of DCT integration leads to the production of images with visible watermarks. The significance of DCT lies in its ability to transform spatial domain data into frequency domain coefficients, enabling imperceptible embedding of watermark information into the host media.

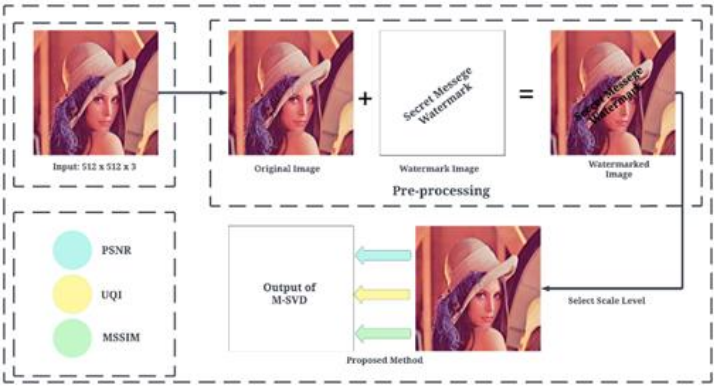

Figure 1. Embedding proposed scheme

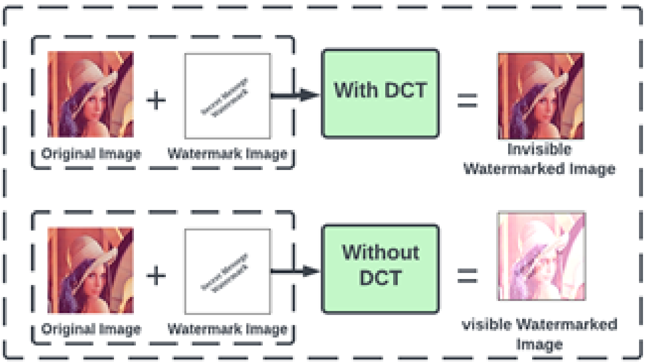

Figure 2. Extracting proposed scheme

2.5. Attacks for result testing

Gaussian noise, recognized as white noise, constitutes a form of stochastic disturbance adhering to a Gaussian (normal) probability distribution [33]. In the context of digital image processing, Gaussian noise is commonly encountered as an unwanted interference that affects the quality and clarity of images [34]. The equation for Gaussian noise can be represented as in (3). Where, $Gaussian\ Noise\ (x, y)$represents the Gaussian noise at pixel location (x, y) in the image. μ represents the mean of the noise distribution, determining the central tendency of the noise values, σ represents the standard deviation of the noise distribution, controlling the spread or dispersion of the noise values, and the Z represents the random variable sampled from a standard normal distribution ($mean = 0$, $standard\ deviation = 1$).

$$Gaussian\ Noise(x, y) = \mu + \sigma \cdot Z \tag{3}$$

Salt and pepper noise denotes a variety of digital image disturbances characterized by arbitrary distribution of black and white pixels dispersed across an image's expanse, resembling grains of salt and pepper [35]. To describe the presence of salt and pepper noise mathematically, we can use (4). Where, OPV means original pixels value, $N(x, y)$ denotes coordinates (x, y) pixel value within the image affected by noise, the parameters p and q represent the probabilities of salt and pepper noise, respectively. A higher value of p and q indicates a higher occurrence of salt or pepper noise in the image.

$$N(x, y) = \begin{cases} 0\ with\ Probability\ p \\ 255\ with\ Probability\ q \\ OPV\ with\ Probability\ 1 - p - q \end{cases} \tag{4}$$

2.6. Calculation evaluation

The proposed method utilizes a comprehensive evaluation approach, employing three image quality metrics: PSNR, UQI, and MSSIM. PSNR furnishes a quantification of the original and manipulated images, affording valuable insights into the accuracy of the reconstructed image [36]. UQI, on the other hand, accounts for both luminance and contrast information, enabling a more holistic assessment of structural similarity [36]. Finally, the application of MSSIM enables a detailed analysis of the structural similarity between images at multiple scales, capturing nuanced variations in image quality [37], [38]. Based on evaluation equation can be seen in (5)–(8). Where, μ_x and μ_y represent the average of pixels between the original and distorted images, σ_x^2 and σ_y^2 represent the variances of pixels between the original and distorted images, respectively. σ_{xy} represents the covariance between pixels of the original and distorted images. $C1$ and $C2$ represent constants to stabilize the division in (5) to (8):

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (I(i,j) - K(i,j))^2 \tag{5}$$

$$PSNR = 10 \log 10 \left(\frac{\max\_pixel\_value^2}{MSE} \right) \tag{6}$$

$$UQI = \frac{4 \cdot \sigma_{xy} \cdot \mu_x \cdot u_y}{(\sigma_x^2 + \sigma_y^2) \cdot (\mu_x^2 + \mu_y^2)} \tag{7}$$

$$MSSIM = \frac{(2\mu_x\mu_y + C1)(2\sigma_{xy} + C2)}{(\mu_x^2 + \mu_y^2 + C1)(\sigma_x^2 + \sigma_y^2 + C2)} \tag{8}$$

3. RESULTS AND DISCUSSION

Based on the proposed method, Table 1 presents the outcomes of visible watermarking, level 1 approach closely approximates the original image and exhibits a discernible degree of embedded watermarking in the watermarked results, these findings are deemed unsuitable for the trial research. Consequently, a need arises for preprocessing techniques such as DCT to be employed, which would facilitate the transformation of visible watermarking into the realm of invisible watermarking. This transition to invisible watermarking is essential to achieve imperceptible integration of watermark information into the host media, ensuring the preservation of visual quality while enhancing it. The test results indicate that at the lowest level, the watermarked images exhibit low MSE values and high PSNR, indicating that the watermarked images at this level possess good quality and closely resemble the original images. However, at the highest level, there is an increase in MSE values and a decrease in PSNR, indicating more significant distortion in the watermarked images. Based on the equation conducted the evaluation results in Tables 2 and 3 encompass the computation of MSE, PSNR, UQI, and MSSIM for each level of the sample images.

Table 1. Sample results for visible watermarking

Original image	Watermark image	Strength level for visible watermarking Alpha Lv 1	Alpha Lv 2	Alpha Lv 3	Alpha Lv 4
					
					
					

Table 2. MSE and PSNR for visible watermarked

Testing	Lena.bmp		Peppers.png		Baboon.jpg		Lena.bmp		Peppers.png		Baboon.jpg	
level	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR
L1	0.0075	20.15	0.0097	20.15	0.0097	20.15	0.9979	0.9790	0.9983	0.9496	0.9972	0.9578
L2	0.094	14.13	0.0387	14.13	0.094	14.13	0.9909	0.9341	0.9932	0.8820	0.9886	0.8874
L3	0.087	10.60	0.087	10.60	0.087	10.60	0.9965	0.8809	0.9792	0.8150	0.9744	0.8161
L4	0.154	8.10	0.154	8.10	0.154	8.10	0.9032	0.8269	0.9359	0.7527	0.9476	0.7503

Table 3. Results evaluation with M-SVD for invisible watermarking

Sample of watermarked	Testing	MSE	PSNR (dB)	UQI	MSSIM
Lena.bmp	Image watermarked	0.0004	82.34	0.9945	0.9961
	Gaussian noise	0.0162	66.03	0.7477	0.1854
	Salt and peppers noise	0.0047	71.42	0.9299	0.4226
	Gaussian+salt and peppers noise	0.0112	67.65	0.8290	0.2422
Peppers.png	Image watermarked	0.0003	82.72	0.9960	0.9952
	Gaussian noise	0.0159	66.10	0.8071	0.1905
	Salt and peppers noise	0.0048	71.34	0.9436	0.4178
	Gaussian+salt and peppers noise	0.0107	67.84	0.8717	0.2495
Baboon.jpg	Image watermarked	0.0004	81.90	0.9916	0.9965
	Gaussian noise	0.0168	65.87	0.6332	0.2261
	Salt and peppers noise	0.0059	70.39	0.8758	0.5111
	Gaussian+salt and peppers noise	0.0126	67.14	0.7316	0.2913

By harnessing the spatial frequency localization capability of DCT and the robustness against common signal processing attacks offered by M-SVD, the proposed method achieves an unparalleled level of imperceptibility and resilience. The joint utilization of these techniques optimally exploits the strengths of both transforms, ensuring a watermarking scheme that not only safeguards the integrity of the host image but also maintains a watermark with minimal distortion and excellent resistance to potential tampering. Based on the proposed method Table 4. Represents the results with M-SVD evaluation and comparison between noise attack and related research.

Based on Figure 3, Figure 3(a) displays a sample image used for watermark embedding, providing the original content to which the watermark will be added. Figure 3(b) represents the watermark image, which contains the distinctive mark or information to be embedded into the sample image. Results of Figure 3(c) and Table 4, the integration of DCT and M-SVD techniques in the context of invisible watermarking has demonstrated exceptional performance, yielding significantly higher PSNR results compared to existing RGB image-based research. This amalgamation signifies a remarkably effective approach for watermarking purposes.

Based on Figure 4, the images depict the results of processing without DCT integration. Figure 4(a) represents invisible watermarking, while Figures 4 (b)-(d) portray invisible watermarking with the addition of Gaussian and salt-and-pepper noise attacks. The analysis results have shown the superiority of the proposed watermarking technique. The elevated PSNR values demonstrated by the proposed approach, when contrasted with the available alternatives, indicate an enhanced level of faithfulness between the images subjected to watermarking and their respective originals. Additionally, the NC values, which provide insight into the consistency and accuracy of the watermark retrieval process, also demonstrate a marked enhancement with the proposed approach. This substantiates the efficacy of the proposed method in achieving a higher degree of robustness and quality in watermark embedding and extraction, making it a more advantageous choice for ensuring image integrity and authentication in various applications.

Table 4. Results of M-SVD against attacks

Image attack	Sample image	Evaluation quality	Results
Gaussian noise	Lena (RGB)	PSNR	66.03 dB
		NC	1
		NCC	0.9908
Salt and peppers noise	Lena (RGB)	PSNR	71.42 dB
		NC	1
		NCC	0.9974
Gaussian noise	Peppers (RGB)	PSNR	66.10 dB
		NC	1
		NCC	0.9925
Salt and peppers noise	Peppers (RGB)	PSNR	71.34 dB
		NC	1
		NCC	0.9976
Gaussian noise	Baboon (RGB)	PSNR	65.87 dB
		NC	1
		NCC	0.9904
Salt and peppers noise	Baboon (RGB)	PSNR	70.39 dB
		NC	1
		NCC	0.9971

(a) (b) (c)

Figure 3. Results of invisible watermarked image; (a) sample image, (b) watermark image, and (c) invisible watermarked image

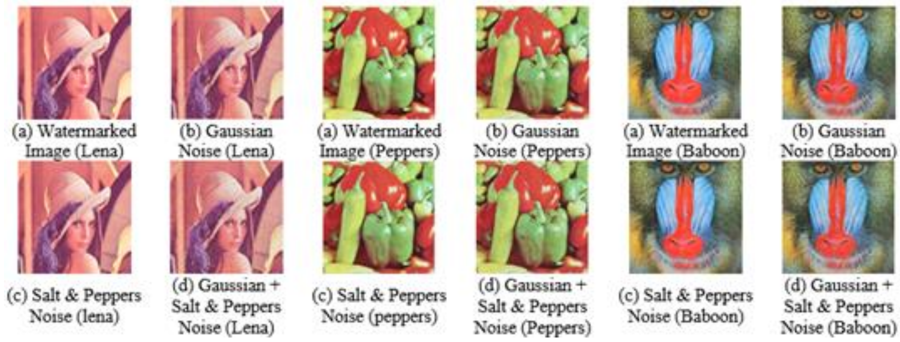

Figure 4. Results of visible watermarked images based on M-SVD; (a) represents invisible watermarking and (b)-(d) invisible watermarking with the addition of Gaussian and salt-and-pepper noise attacks

Based on Table 5, the computed PSNR, NC, and NCC values, the researcher adjusted them according to the scaling factor (alpha) levels established in the previous studies by Khanam *et al.* [28], Yasmeen and Uddin [29]. The research by Khanam *et al.* [28] focuses on non-blind symmetric image watermarking techniques using DWT and DCT for ownership protection in multimedia data. Their method incorporates a secret key for watermark embedding and extraction, enhancing system security. While achieving promising results with PSNR ranging from 45.23 to 51.89 and NC from 0.8561 to 0.9778, their approach shows slightly lower PSNR values and NC range compared to our proposed method. On the other hand, Yasmeen and Uddin [29] introduce a hybrid watermarking scheme integrating DWT and SVD, achieving a PSNR of 34.73 dB and a correlation coefficient of 0.9975 on Lena images. In contrast, our study presents an enhanced method for evaluating non-blind watermarking quality, employing both visible and invisible watermarking techniques based on M-SVD and DCT principles. By integrating the M-SVD technique, our approach aims to enhance the assessment procedure for watermarked images, achieving high PSNR values of 82.34 dB for Lena, 82.72 dB for Peppers, and 81.90 dB for Baboon images, alongside perfect correlation coefficients, thus demonstrating superior performance in maintaining image quality and watermark integrity.

Table 4 elucidates the performance metrics of M-SVD against various image attacks, including Gaussian and Salt and Pepper noise, across different sample images such as Lena, Peppers, and Baboon shown in Figure 5. The evaluation quality indicators, namely PSNR, NC, and NCC, manifest robust results with high PSNR values and nearly perfect NC and NCC scores, underscoring the efficacy of M-SVD in preserving image quality and integrity amidst adversarial attacks. In contrast, Table 5 juxtaposes the proposed DCT+M-SVD method against seminal studies by Khanam *et al*. [28], Yasmeen and Uddin [29], employing distinct watermarking techniques like SVD+FWHT and SVD+DWT, respectively. The comparative analysis reveals a significant enhancement in PSNR values for the proposed method across all sample images, substantiating its superiority in maintaining image quality and achieving optimal watermarking efficiency.

Table 5. Comparison results of PSNR, NCC, and NC with other studies

Researcher	Sample watermarked	Method	PSNR (dB)	NC
Proposed method	Lena	DCT+M-SVD	82.34	1
	Peppers		82.72	1
	Baboon		81.90	1
Khanam *et al*. [28]	Lena	SVD+FWHT	50.04	1
	Peppers		49.78	1
	Baboon		51.56	1
Yasmeen and Uddin [29]	Lena	SVD + DWT	34.73	0.9975

Figure 5. Results of invisible watermarked images based on DCT+M-SVD

4. CONCLUSION

Based on the proposed method and the results outcomes, the present study has achieved notable contributions in the field of watermarking. The innovative incorporation of DCT and M-SVD techniques in the watermarking process has yielded processing results remarkably akin to the original images, establishing a noteworthy novelty in the domain of invisible watermarking. In the case of visible watermarking, the assessment of MSE values unveiled a range from 0.0075 to 0.154, accompanied by PSNR values spanning from 8.10 to 20.15. Particularly, the image "Lena" demonstrated commendable scores in the realm of visible watermarking, surpassing those of "peppers" and "baboon". Conversely, the application of the DCT and M-SVD methods in the non-blind, invisible watermarking investigation produced exceptional results. This approach achieved the highest outcomes, with the image "peppers" attaining the superlative MSE and PSNR values, registering at 0.0003 and 82.72 dB, respectively. In summation, this study underscores the potency of the DCT and M-SVD techniques in bolstering watermarking processes, particularly in the context of invisible watermarking. Further comparisons and analyses are recommended to establish the proposed approach's efficacy concerning other methods in the watermarking domain. For future research, several promising directions can be explored to further enhance and extend the proposed watermarking method. Firstly, investigating advanced noise reduction techniques, such as deep learning-based denoising algorithms, could potentially lead to even higher PSNR values and better visual quality of the watermarked images. Additionally, exploring the use of adaptive watermarking schemes that can dynamically adjust the strength of the watermark based on image content and characteristics may improve the robustness and imperceptibility of the embedded watermarks.

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