[Iraqi Journal for Computer Science and Mathematics](https://ijcsm.researchcommons.org/ijcsm)

Volume 5 | Issue 4 Article 3

2024

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Recommended Citation

Shubuh, Syafiqul; Ernawan, Ferda; Amrullah, Agit; and Wahyu, Prajanto (2024) "Robust Image Watermarking Based on IWT-DCT-SVD for Copyright Protection," *Iraqi Journal for Computer Science and Mathematics*: Vol. 5: Iss. 4, Article 3.
DOI: https://doi.org/10.52866/2788-7421.1201
Available at: https://ijcsm.researchcommons.org/ijcsm/vol5/iss4/3

IRAQI JOURNAL FOR COMPUTER SCIENCE AND MATHEMATICS 2024;5:27–35

RESEARCH ARTICLE

Robust Image Watermarking Based on IWT-DCT-SVD for Copyright Protection

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ABSTRACT

The rapid advancement of technology has resulted in many intellectual works, in the form of images requiring copyright protection to prevent unauthorized use by irresponsible parties. This research examines the hybrid watermarking method that utilises IWT-DCT-SVD domain to enhance the durability of the embedded watermark. The host image is used as the input for the R-Level process, if the watermark logo is small, then the cover image is computed by 3-level of IWT. Whereas, the watermark logo has a large size, the cover image is then computed by 1-level of IWT. The watermark logo is embedded into the singular value of IWT-DCT-SVD for copyright protection. The proposed technique is further assessed and verified by using various attack types. The test findings indicate that the proposed watermarking technology exhibits excellent invisibility and robustness performance, surpassing prior studies. The proposed scheme achieved a high SSIM value of 0.99943, good robustness for NC value from various attacks. These methods are anticipated to provide an alternative answer to watermarking techniques for enhancing the robustness of embedded digital watermarks.

Keywords: Watermark, Copyright protection, Image Watermarking, IWT, DCT, SVD

1. Introduction

The rapid development of technology has necessitated the implementation of copyright protection for many intellectual works, such as images, to avoid their misuse by irresponsible entities. Utilising watermarking techniques is a highly effective approach to safeguard copyright in digital images.

Digital image watermarking is a method employed to insert watermark information into various forms of multimedia content, including text, images, audio, and video. Once integrated, this data can be retrieved or identified from the goods that have been marked with a watermark. The objective is to safeguard the host image by incorporating an imperishable or unmodifiable watermark that cannot be eradicated or substituted by unauthorized entities [1].

The technique of digital image watermarking can be classified into spatial domain and frequency domain techniques, including DCT, DWT, IWT, RDWT, and others. In spatial domain watermarking, the watermark is embedded by making tiny modifications or alterations to the pixel values of the chosen host image directly [2]. On the other hand, frequency domain approaches, sometimes referred to as domain transform, convert the watermark into coefficients represented as signals inside the host image. Techniques in the spatial domain, such as SVD and LSB, offer straightforward embedding and quicker processing. However, they are less resistant to attacks. In contrast, frequency domain approaches provide better invisibility and resilience [3].

Researchers have proposed hybrid digital image watermarking approaches to produce the best

Received 17 December 2023; accepted 25 March 2024.
Available online 25 November 2024

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https://doi.org/10.52866/2788-7421.1201

outcomes and boost durability. A multitude of scholars integrate and enhance spatial domain and domain transform methodologies. In the study conducted by J. Liu et al. [4], a mix of DWT, HD, and SVD was employed to bolster resistance against diverse attacks. In addition, T. Zhu et al. [5] conducted research that utilized optimized methodologies using SVD and IWT to enhance imperceptibility and resilience, resulting in improved outcomes. In addition, the work conducted by M. Begum et al. [6] employed a hybrid approach utilizing DCT, DWT, and SVD to address weaknesses and improve resilience [6].

The selection of either spatial domain or frequency/transform domain techniques in digital image watermarking is contingent upon the objectives and criteria. Every approach possesses its own set of restrictions, benefits, and drawbacks [2]. The study conducted by Liu et al. [4] demonstrated that by utilising HD and SVD transformations in the DWT domain, watermarking techniques can be optimised. The results indicated a favourable balance between the ability to withstand attacks and the level of visibility for watermarks of different sizes. Nevertheless, the utilisation of the watermarking technique alongside HD matrix decomposition necessitates a predetermined watermark size, hence restricting adaptability and applicability in situations that demand varying watermark sizes. Conversely, the DWT possesses the benefit of precisely depicting images at different degrees of detail by employing integers and fractions. However, this characteristic renders it susceptible to wavelet coefficient attacks. Hence, the resilience to attacks can be further enhanced by integrating additional watermarking methodologies.

This paper presents an image watermarking based on IWT-DCT-SVD methods. The watermark image is computed by SVD, and the host image is transformed by using IWT-DCT-SVD methods. The watermark image is then embedded into the singular value of IWT-DCT-SVD. The experiments will be evaluated in terms of imperceptibility and robustness of embedded watermark against various attacks. The proposed scheme is expected to achieve high imperceptibility and robustness performance for copyright protection.

2. Related works

The existing watermarking schemes have been investigated hybrid transform methods in image watermarking to achieve high robustness. The existing solutions showed combination of transform methods that can resist against image processing attacks. The balancing between imperceptibility and robustness performance becomes challenges, even when dealing with various watermark sizes.

L. Junxiu et al.'s study [4] presented a novel mix of techniques combining SVD, HD, and DWT. Subsequently, this methodology was contrasted with alternative investigations conducted amidst diverse forms of attacks. The experimental findings demonstrated a favourable balance between the ability to withstand challenges and the level of clarity, even when dealing with watermarks of different dimensions. Nevertheless, the utilisation of the watermarking technique alongside HD matrix decomposition necessitates a predetermined watermark size. This constraint can hinder adaptability and the utilisation of the technique in situations that need varying watermark dimensions.

The study conducted by T. Zhu et al. in 2021 [5] delves more into the advancement of a refined digital image watermarking method utilizing SVD and IWT. The research findings demonstrate robust resistance to attacks and image alterations, enabling accurate extraction of watermarks with great precision. In the following study, conducted by M. Begum et al. [6], DCT coefficients are generated by applying DCT to image blocks, which are then used as the place for watermark embedding with value or bit alteration techniques. Afterwards, the DWT is utilised to acquire sub-bands that possess distinct resolutions and frequencies. SVD is employed to calculate the singular values in every sub-band of the DWT. The findings demonstrated strong resistance to various attacks, including compression, filtering, cropping, and other forms of attack.

Saqib Ali Nawaz et al. conducted research [7] on a hybrid approach that combines IWT and SVD to develop a strong watermarking algorithm. The process involves decomposing the host image into one integer wavelet transform IWT to generate four sub-bands. Subsequently, the SVD transformation is applied to these four sub-bands. The watermark image information is then embedded directly into the singular values of the four sub-bands of the host image. A proposed authentication system is utilized throughout the process of embedding watermarks. Empirical evidence suggests that this algorithm has strong perceptibility and resilience against diverse forms of attacks.

Li et al. [8] and colleagues conducted a study with the objective of creating a watermarking algorithm that is highly resistant to attacks and preserves the visual quality of images. The approach employs a fusion of LWT and Hessenberg decomposition. This study greatly contributes to the advancement of watermarking techniques by utilizing the combination of LWT and Hessenberg Decomposition. By employing this groundbreaking method, the scheme can generate digital images that possess both robust security and exceptional visual fidelity.

In their study, Abdulrahman et al. [9] devised a resilient hybrid DCT and DWT watermarking algorithm specifically designed for colour images. The transformation domain is obtained by applying the DCT on colour images. Subsequently, the DWT is performed on each colour channel, resulting in the division of each channel into many sub-bands with varying resolutions. The research findings demonstrate that the devised method possesses robust resilience against attacks while also preserving exceptional visual fidelity for colour images.

Ernawan et al. [10] introduced a methodology for image watermarking that leverages the IWT and SVD. The objective of this scheme is to fortify the durability and undetectability of watermarked images in the face of diverse attack vectors. This method utilises pixel variance to identify the specific sites for embedding and alters the U matrix component of the IWT-SVD. The proposed scheme's effectiveness is supported by empirical evidence. Nevertheless, the proposed scheme exhibits marginally reduced SSIM values for certain images when compared to the reference scheme. Furthermore, the suggested approach offers less distortion in the extracted watermark when subjected to median and average attacks.

3. Proposed watermarking scheme

The objective of this study is to create a highly effective and resilient image watermarking technique by employing the integration of IWT-DCT-SVD. The approach prioritises the enhancement of the watermark embedding and extraction procedures, considering the image's quality and its ability to withstand typical attacks in image watermarking.

3.1. Proposed Watermark embedding

In Fig. 1, the process of embedding process is illustrated to represent the embedding process.

Step 1: The host image is used as the input for the R-Level process, where it is transformed into the IWT domain to extract wavelet coefficients at different scales and orientations. This results in four frequency sub-bands: LL, LH, HL, and HH.

Step 2: Perform 8 × 8 DCT transformation into the LL sub-band.

Step 3: DCT coefficients are computed by SVD.

Step 4: The watermark is embedded into singular value of SVD as follows:

$$HSw\_hat = HSw + alpha.^{*}Sw$$

where HSw is the singular value of the cover image, Sw denotes singular value of watermark logo and alpha is the scaling factor obtained from the trade-off between invisibility and robustness.

Step 5: Perform inverse SVD to obtain the watermarked image.

Step 6: To reconstruct the watermarked image, the SVD values are computed by inverse DCT. Thus, the coefficients are computed by inverse R-level IWT.

Step 7: Generate the watermarked image.

3.2. Proposed watermark extraction

Step 1: The watermarked image is transformed by using R-Level IWT to obtain four frequency sub-bands: LLw, LHw, HLw, HHw.

Step 2: DCT transformation is performed into the LL DCT sub-band of the watermarked image.

Step 3: DCT coefficients are computed by using SVD.

Step 4: The extracted watermark from singular value is computed by:

$$Sw\_hat = (HSbw\_hat - HSw)./alpha$$

where $HSbw$ is the singular value of watermarked image, HSw denotes the singular value of the cover image.

Step 5: The extraction of singular values Sw_hat is then computed by inverse SVD to revert the watermark image.

Step 7: Generate the extracted watermark.

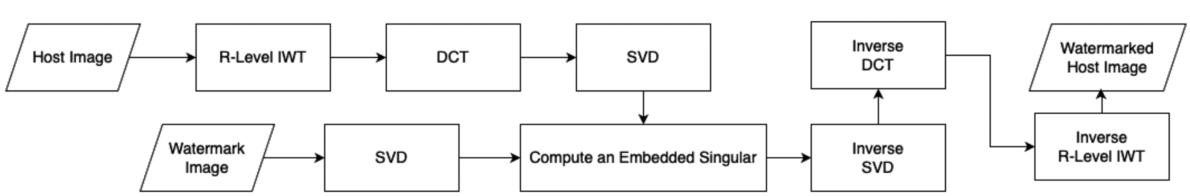


Fig. 1. Proposed embedding process.

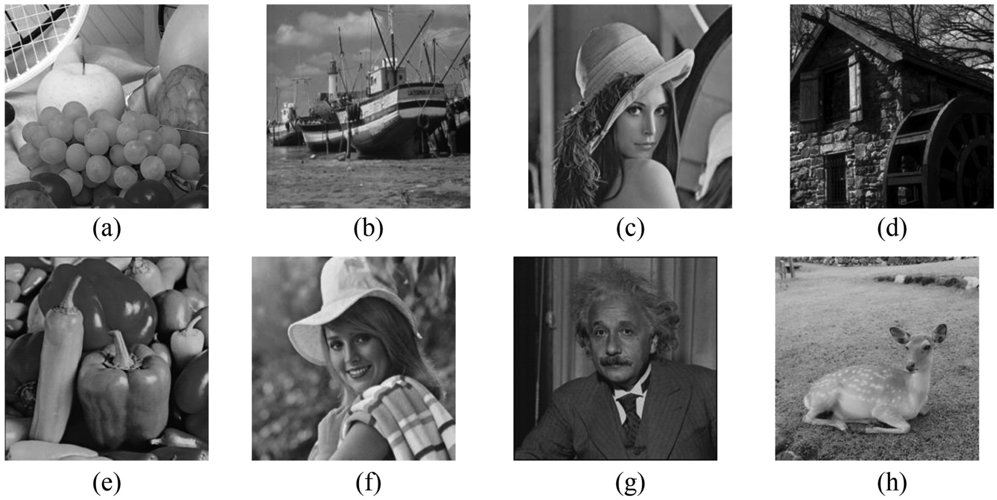


Fig. 2. Host images: (a) Fruits, (b) Boat, (c) Lena, (d) Old mill, (e) Peppers, (f) Elaine, (g) Einstein, (h) Deer.

3.3. Evaluation

The invisibility of the watermarked image is measured by PSNR and SSIM evaluation. PSNR is defined by [11–14]:

$$PSNR = 10log_{10}\frac{S^2}{\frac{1}{M\cdot N}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}(cv(x,y)-wr(x,y))} \tag{1}$$

where S represents the maximum intensity value of 255 on an 8-bit image, cv is the cover image, and wr is the watermarked or recovered image. The SSIM value ranges between 0 and 1, where a value of 1 indicates perfect structural similarity between two images. A higher SSIM value signifies a closer match in the structure and texture of the two images. SSIM is defined by [15–17]:

$$SSIM(x,y) = \frac{(2\mu_x + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_y^2 + \sigma_y^2 + c_2)} \tag{2}$$

4. Experimental results

The performance and efficacy of the proposed watermarking technique are evaluated during the testing portions of this investigation. The objective is to assess the effectiveness of the suggested technology in safeguarding images against potential attacks or manipulations, while also guaranteeing that the embedded watermark does not noticeably diminish the visual quality of the image.

The purpose of the testing is to assess the resilience of the watermarking technique against different types of attacks or manipulations, including compression, filtering, and cropping. This stage entails the implementation of targeted attacks or alterations on watermarked images to assess the feasibility of preserving the watermark. An effective watermarking system should possess the capability to preserve the watermark even in the face of an attack.

This study aims to evaluate and analyse the IWT-DCT-SVD watermarking technique in terms of its embedding and extraction procedures. For testing purposes, a total of eight grayscale images with dimensions of 512 × 512 pixels are utilised as host images, as depicted in Fig. 2. The watermark images utilised are UNM logos with dimensions of 256 × 256, 128 × 128, and 64 × 64 pixels to facilitate a more distinct comparison of outcomes and improve the visualisation of the research findings, as depicted in Fig. 3.

Furthermore, an evaluation of the watermarking technique utilizing IWT-DCT-SVD is performed on many preselected host images. The UNM logo with various dimension sizes is selected as watermarks in the experiments. The UNM logo is used for many significant reasons and in different situations. Additionally, a UNM logo watermark improves the university's brand recognition and visibility. The UNM logo watermark is then embedded using different size schemes, as shown in Table 1. The evaluation of the watermarked digital images is performed by

Fig. 3. Watermark image (256 × 256, 128 × 128, 64 × 64).

Table 1. PSNR and SSIM values of the proposed scheme.

	PSNR Watermark size			SSIM Watermark size		
Image	256 × 256	128 × 128	64 × 64	256 × 256	128 × 128	64 × 64
Fruits	38.4913	38.496	38.5203	0.99918	0.99919	0.99922
Boat	38.3369	38.3543	38.3847	0.99947	0.99951	0.99952
Lena	38.29	38.298	38.3315	0.99943	0.99943	0.99943
Old mill	38.2659	38.2783	38.2904	0.98684	0.9868	0.98674
Peppers	38.2256	38.2429	38.2632	0.99908	0.99906	0.99902
Elaine	38.21	38.219	38.2535	0.99957	0.99957	0.99957
Einstein	38.23	38.2405	38.2449	0.99903	0.99903	0.99902
Deer	38.1805	38.196	38.2196	0.9996	0.99965	0.99969

measuring their quality PSNR, SSIM, and NC with a specific α value of 0.015.

The NC value is 1 when the watermarked host image is not subjected to any attacks. These findings demonstrate that the suggested watermarking technology demonstrates excellent imperceptibility and fulfils the criteria for imperceptibility in both subjective and objective evaluations. The durability of the suggested technique is assessed by the introduction of attacks. The watermarked images in Table 2 exhibit highly favourable outcomes when subjected to attacks, as nearly all of them maintain visual clarity even after the attacks.

The extracted watermark pictures that have been attacked are shown in Table 2 to evaluate their quality. For all image sizes, the NC values found in Table 2 are advantageous against attacks such motion blur, sharpening, shifting, Wiener, median, Gaussian low-pass, average, and speckle filters, as well as Gaussian noise and noise variations like salt and pepper and speckle noise. Nevertheless, the suggested technique exhibits inferior values for all test sizes when subjected to the histogram equalization attack. A minimal NC value of 0.7 dB is considered the standard for high quality [4]. The histogram equalization attack specifically targets the colour intensity and contrast of the image, resulting in substantial alterations to the watermarked image. Consequently, the watermark becomes undetectable, and the embedded watermark appears blurry due to the modification of the rather intense colour intensity during the histogram equalization procedure.

4.1. Comparison of NC values

In this analysis, we will refer to prior studies that utilised the Lena host image with a significance level of α 0.05. The dimensions of the grayscale host image are 512 × 512, while the watermark images have dimensions of 256 × 256, 128 × 128, and 64 × 64. The effectiveness of the proposed technique will be assessed and compared by analysing the NC values subjected to different types of attacks, such as Wiener filter, Gaussian noise, Gaussian filter, median filter, average filter, salt & pepper, speckle noise, JPEG2000, JPEG compression, histogram equalisation, motion blur, sharpening, and angle-shift as shown in Table 3.

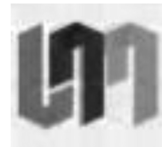
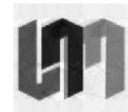
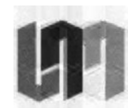
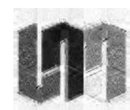
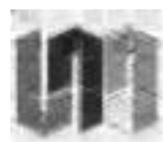
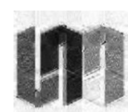
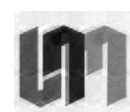
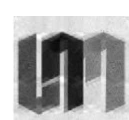
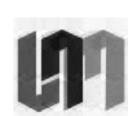
To assist the comparison of the tested attack techniques, we will give visual graphics that compare the NC values between earlier research and the suggested technique for 13 distinct types of attacks and various image sizes. These sizes include 256 × 256, 128 × 128, and 64 × 64 pixels.

The comparison of NC values for the proposed technique with the implementation of 13 attacks can be viewed in Table 4. The results show improvements and modest decreases in comparison to the previous study across various watermark sizes. Nine attack strategies exhibit enhancements at different scales, including Wiener filter, median filter, average filter, Gaussian noise, salt & pepper, JPEG compression, JPEG2000, motion blur, and angle shift. In two separate attacks, specifically the Gaussian low-pass filter and speckle noise, there are only reductions observed in specific test sizes. Among the various attack strategies, only histogram equalisation, sharpening, and testing without attacks exhibit decreases across varied test sizes.

Both histogram equalisation and sharpening attacks result in a drop in all test sizes. However, the resultant NC values remain above 0.85 dB, which is regarded satisfactory. A minimum NC value of 0.7 dB is considered good according to the standard [4]. The proposed technique is vulnerable to a histogram equalisation attack, which can result in notable alterations to the colour intensity and contrast of the image. As a consequence, the watermark becomes imperceptible due to the equalisation process, which modifies the colour intensity and blurs the embedded watermark.

Conversely, in the context of a sharpening attack, the act of inserting the watermark modifies the intensity of pixels in the image, potentially causing

Table 2. Visual of extracted watermark from various attacks.

	NC Value			Watermarked image		
Attacks	256 × 256	128 × 128	64 × 64	256 × 256	128 × 128	64 × 64
Wiener filter	0.99769	0.99922	0.99951			
Median filter	0.99409	0.99791	0.99894			
Gaussian low-pass filter	0.97888	0.99283	0.99821			
Average filter	0.97851	0.99264	0.99816			
Gaussian noise	0.99689	0.99892	0.99924			
Salt & pepper noise	0.99909	0.99937	0.99944			
Speckle noise	0.98992	0.99762	0.99817			
JPEG compression	0.99921	0.99935	0.99941			
JPEG2000 compression	0.99895	0.99931	0.99933			

(*continued on next page*)

Table 2. Continued.

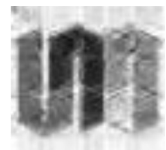
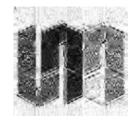
	NC Value			Watermarked image		
Attacks	256 × 256	128 × 128	64 × 64	256 × 256	128 × 128	64 × 64
Histogram equalization	0.34043	0.33668	0.32996			
Motion blur	0.96226	0.97713	0.99333			
Sharpening	0.99873	0.99948	0.99964			

Table 3. Comparison of NC values under various attacks.

	256 × 256		128 × 128		64 × 64	
Attacks	Liu et al.[4]	Proposed	Liu et al.[4]	Proposed	Liu et al.[4]	Proposed
No Attack	1.0000	0.99989	1.0000	0.99989	1.0000	0.99989
Wiener filter	0.9682	0.9992	0.9880	0.99978	0.9979	0.99989
Median filter	0.9685	0.99816	0.9905	0.99962	0.9993	0.99981
Gaussian low-pass filter	0.9749	0.98708	0.9973	0.99618	0.9992	0.99937
Average filter	0.9294	0.98682	0.9539	0.99604	0.9911	0.99937
Gaussian noise	0.9864	0.99638	0.9987	0.99982	0.9997	0.99993
Salt & pepper noise	0.9985	0.99952	0.9996	0.99997	0.9997	0.99997
Speckle noise	0.9981	0.99264	0.9998	0.99943	0.9998	0.99991
JPEG compression	0.9998	0.99998	0.9999	0.99998	0.9997	0.99995
JPEG2000 compression	0.9997	0.99978	0.9999	0.99995	0.9998	0.99996
Histogram equalizatin	0.9924	0.85923	0.9911	0.85503	0.9878	0.85316
Motion bluar	0.8322	0.96991	0.8569	0.97892	0.9147	0.99378
Sharpening	1.0000	0.99899	1.0000	0.99972	1.0000	0.99994
Angle - shift	0.9496	1	0.9422	0.99952	0.9306	0.9985

disturbance or harm to the patterns employed in the watermarking approach. Consequently, the imbedded watermark loses its effectiveness.

4.2. Benchmarking with the existing schemes

Comparing test results with other research in image watermarking is used to assess the performance of a proposed watermarking technique compared to techniques that have been previously documented in the reference literature as shown in Fig. 4. The main objective is to assess the degree to which the suggested technique outperforms or underperforms in comparison to existing procedures.

Through doing comparisons, one may verify the efficacy and proficiency of the newly offered technique. This can help ensure that the recommended strategy truly provides enhancements and enables the identification of the merits and drawbacks of each technique. It can be used as a benchmark for the advancement of more sophisticated and resilient watermarking methods in future studies. In the domain of image watermarking, safeguarding copyright and ensuring image authenticity is of utmost importance, as it directly influences the resilience of a technique against various hostile attacks. Hence, doing a comparative analysis with different methodologies can assist in evaluating the resilience of the suggested strategy against such attacks.

Based on the data presented in Table 4, a comparative analysis with previous studies utilising the identical grayscale watermark image reveals the subsequent findings: In the study conducted by Liu et al. [4], it was found that the highest value is attained

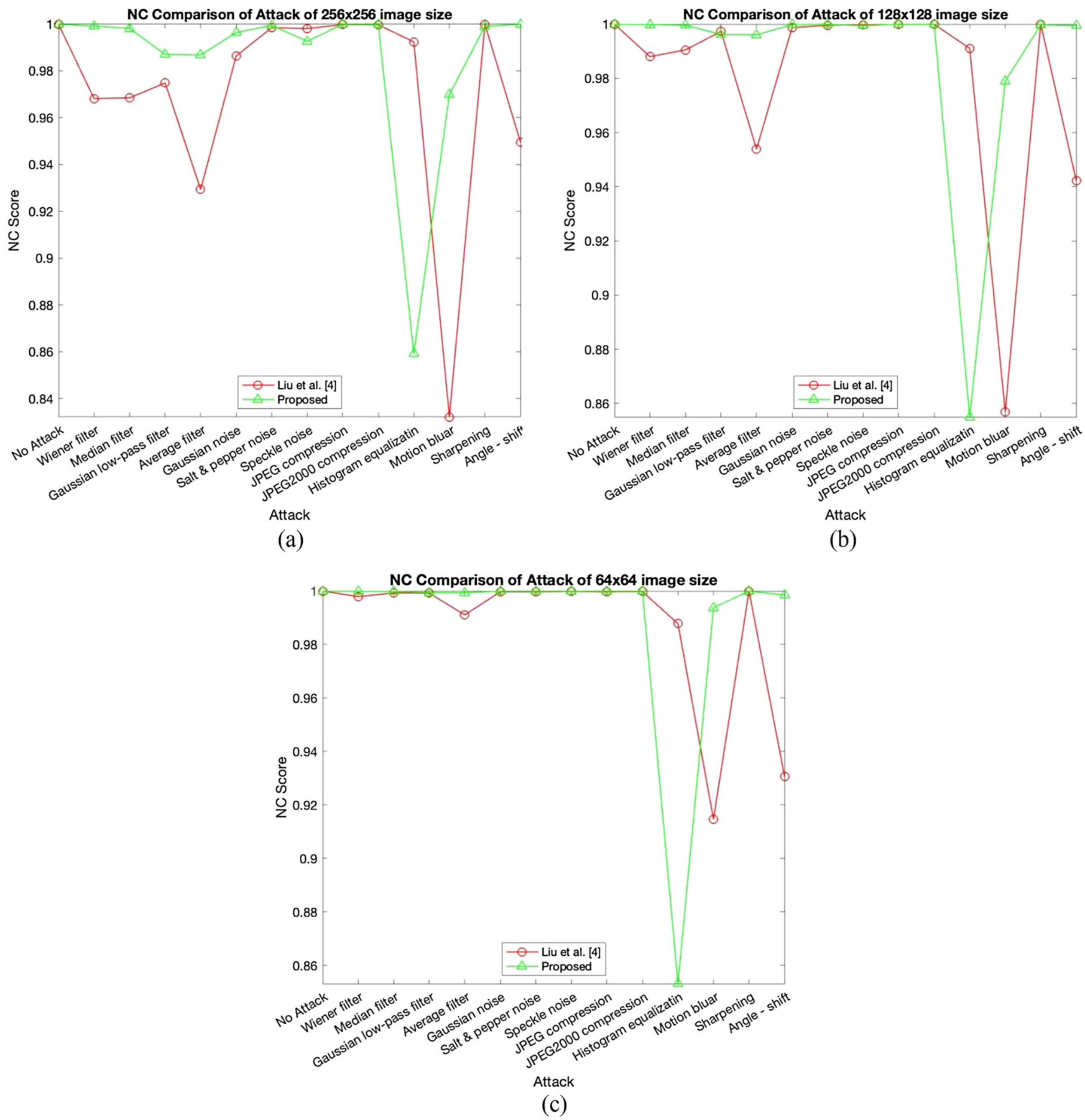


Fig. 4. NC Comparison for different watermark sizes.

Table 4. The Comparison of the proposed scheme with the existing schemes.

Information	Liu et al.[4]	Wu et al. [18]	Ernawan & Ariatmanto[10]	Proposed
Watermark type	Grayscale	Grayscale	Grayscale	Grayscale
Metode	DWT-HD-SVD	4DWT-DCT-SVD	IWT-SVD	IWT-DCT-SVD
PSNR	38.2477	46.3805	–	38.3315
SSIM	0.9991	0.9979	0.9900	0.99943
No Attack	1.0000	0.9956	1.0000	0.99989
Gaussian noise	0.9997	0.9188	0.9990	0.99993
Salt & pepper noise	0.9997	0.9141	0.9883	0.99997
JPEG compression	0.9997	0.9943	1.0000	0.99995

alone in the absence of any attack, using DWT-HD-SVD. The study conducted by J. Wu et al. [18] utilised the 4DWT-DCT-SVD approach to determine the highest value for PSNR. The study conducted by F. Ernawan et al. [10] demonstrates that the IWT-SVD technique yields the highest value for NC when there is no attack and during JPEG compression. The research conducted using the IWT-DCT-SVD technique yields optimal outcomes for SSIM and NC in various assault scenarios, including Gaussian noise and salt & pepper noise. The comparative analysis indicates that the proposed technique is more resilient against different forms of attacks compared to numerous existing research approaches.

5. Conclusion

This study examines the effectiveness of the IWT-HD-SVD hybrid watermarking technique compared to the existing schemes. The watermark is embedded into the singular value of IWT-HD-SVD. The proposed scheme has been evaluated and validated with a watermark in three different sizes: 256×256, 128×128, and 64×64 pixels. The durability of the suggested technique has been tested against various forms of attacks. The outcomes demonstrate that the suggested strategy accomplished strong robustness against Gaussian noise addition and Salt & Pepper noise as well as good imperceptibility. With an SSIM score of roughly 0.999, the imperceptibility performance demonstrates that the watermarked image is more similar to the original.

Acknowledgement

This work was supported by the Ministry of Higher Education for providing financial support under Fundamental Research Grant Scheme (FRGS), No FRGS/1/2023/ICT04/UMP/02/1 (University reference RDU230121).

Conflicts of interest

The author declares no conflict of interest.

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