Indonesian Journal of Electrical Engineering and Computer Science
Vol. 33, No. 1, January 2024, pp. 581~590
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v33.i1.pp581-590

In-depth exploration of digital image watermarking with discrete cosine transform and discrete wavelet transform

Md. Apu Hosen[1,2], Shahadat Hoshen Moz[1,2], Sk. Shalauddin Kabir[1], Md. Nasim Adnan[1], Syed Md. Galib[1]
[1]Department of Computer Science and Engineering, Jashore University of Science and Technology, Jashore, Bangladesh
[2]Department of Computer Science and Engineering, Northern University of Business and Technology Khulna, Khulna, Bangladesh

Article Info

Article history:

Received Jul 25, 2023
Revised Oct 25, 2023
Accepted Nov 21, 2023

Keywords:

Digital watermarking
Discrete cosine transformation
Discrete wavelet transformation
Robustness
Security

ABSTRACT

Digital image watermarking is a crucial technique used to protect the integrity and ownership of digital images by embedding imperceptible watermarks into the image content. This review concentrates on the utilization of discrete cosine transform (DCT) and discrete wavelet transform (DWT) in digital image watermarking schemes. DCT, widely used in image compression like JPEG, is an attractive choice for watermarking, modifying DCT coefficients with minimal impact on image quality. On the other hand, DWT offers multiresolution representation, enabling better localization and robustness against attacks. DWT-based methods use wavelet coefficients to embed watermarks in specific frequency bands or image regions. The review examines the strengths and weaknesses of DCT and DWT in digital image watermarking, exploring algorithms and approaches proposed in the literature. It also addresses challenges like attacks, synchronization, and robustness to image processing. Additionally, a comparative analysis of DCT and DWT-based methods considers imperceptibility, robustness, capacity, and computational complexity. By offering valuable insights, this review aids researchers and practitioners in implementing secure and efficient digital image watermarking solutions.

Corresponding Author:

Syed Md. Galib
Department of Computer Science and Engineering, Jashore University of Science and Technology
Jashore-7408, Bangladesh
Email: galib.cse@just.edu.bd

1. INTRODUCTION

With the rapid advancement of digital media and its widespread distribution, safeguarding the authenticity and security of digital images has become a matter of utmost importance. Digital image watermarking has emerged as a prominent solution to tackle issues like copyright infringement and unauthorized manipulation. This method involves discreetly embedding information, referred to as watermarks, into the image, enabling the verification of authenticity, ownership, and unauthorized usage tracking [1].

Removing a watermark from watermarked data poses a significant challenge, as traditional methods like display or conversion into different file formats are ineffective in its elimination. Even after an attempted attack, valuable information about the transformation can still be extracted from the watermark. It is crucial to differentiate digital watermarking from other technologies such as encryption [2]. Digital image watermarking techniques possess the ability to withstand various processes, including digital-to-analog conversion, compression, changes in file formats, as well as re-encryption and decryption procedures. This resilience makes watermarking a viable and robust alternative or complement to cryptography. By directly embedding the information into the content, it becomes resistant to removal through normal usage [3].

Within the realm of digital image watermarking, transform domain techniques have gained significant popularity for their ability to achieve imperceptibility and robustness. Two widely used transform domains for watermarking are the discrete cosine transform (DCT) and the discrete wavelet transform (DWT). The DCT, which is commonly utilized in image compression algorithms like JPEG, facilitates an efficient frequency domain representation [4]. On the other hand, the DWT offers a multiresolution decomposition of an image, enabling superior localization and resilience against common attacks [5].

The main purpose of this research article is to present a comprehensive review and comparative analysis of digital image watermarking techniques based on DCT and DWT. The objective is to assess the strengths and limitations of each transform domain and analyze the performance of existing algorithms proposed in the literature. Through the examination of various approaches, the article aims to identify the primary challenges faced in watermarking techniques, including attacks, synchronization, and robustness to image processing operations. Additionally, it seeks to conduct a comparative analysis of DCT and DWT-based watermarking schemes, providing insights for researchers and practitioners to understand the trade-offs involved in choosing between DCT and DWT based on their specific watermarking requirements.

The remainder of this work is structured as follows: Section 2 provides a concise overview of the watermark technique and its improvements. Section 3 offers a comprehensive literature survey. In Section 4, a comparative analysis is conducted. Finally, Section 5 will conclude this paper.

2. WATERMARK TECHNIQUE

The process of watermark embedding typically entails the combination of an original host image and the watermark image. An algorithm designed for watermark embedding is used to insert the watermark image into the host image, giving rise to a watermarked image. This watermarked image is subsequently transmitted through a communication network and may encounter various attacks. Following this, a watermark extraction algorithm is employed to retrieve the watermark image from the watermarked image [6]. The visual representation of this framework is illustrated in Figure 1. Watermarking techniques, employed to safeguard digital media integrity and address copyright infringement concerns, can be broadly categorized into two main approaches: spatial domain techniques and transform domain techniques [7].

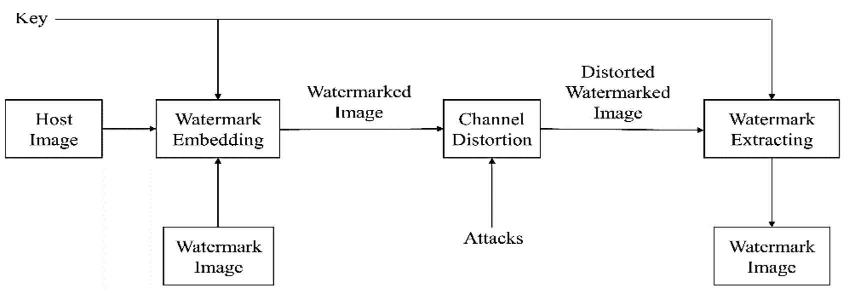

Figure 1. Basic framework for incorporating and retrieving watermark images

2.1. Spatial domain techniques

In spatial domain watermarking, the process involves directly manipulating the pixel values of the host media, such as images or videos. Techniques within this domain focus on modifying the pixel values within the spatial domain of the media itself [8]. Various methods can be used, including altering the least significant bits (LSB) of pixel values, adjusting pixel intensities, or utilizing visual masking techniques to conceal the watermark within the image [9]. Spatial domain techniques are relatively simple to implement and can be computationally efficient. However, they may be more susceptible to attacks like geometric transformations, cropping, or compression, which could potentially compromise the visibility or robustness of the watermark. Geometric transformations can distort the watermark or shift its position, while compression algorithms may introduce artifacts that interfere with the watermark. Despite these limitations, spatial domain techniques offer ease of use and efficiency, making them suitable for real-time applications or scenarios with limited computational resources [10]. When selecting spatial domain watermarking techniques, it is important to consider the desired level of visibility, robustness, and the specific requirements of the application or the media being watermarked [11].

2.2. Transform domain techniques

Transform domain watermarking revolves around converting the host media, such as images or videos, into an alternate domain using techniques like the discrete fourier transform (DFT), discrete cosine transform (DCT), discrete wavelet transform (DWT), or other frequency-based or spatial frequency-based transforms [12]. By utilizing these transforms, the pixel-based representation of the media is converted into a frequency-based representation, unveiling the frequency components within the data. The watermark is subsequently embedded by altering the coefficients or frequency components in this transformed domain [13].

2.3. Enhancing watermark with transform domain

Enhancing watermarks with transform domain techniques represents a formidable strategy, delivering a host of benefits that fortify the protection of digital assets. This approach excels in distributing watermark information across multiple coefficients within the frequency domain, endowing the watermark with heightened resilience against image manipulations like rotation, scaling, and compression, which are common challenges in the digital realm [14]. Moreover, by cleverly utilizing the properties of human visual perception, these techniques embed the watermark with a subtlety that minimally affects the visual quality of the media. This harmonious balance between security and content quality is further accentuated by the versatility of transform domain watermarking, extending its application across various digital media forms, including images, audio, and video. As such, it becomes an indispensable tool for content creators and distributors, safeguarding their valuable assets and ensuring the authenticity and integrity of their content in the ever-evolving digital landscape [15].

3. LITERATURE REVIEW

As computer networks, the internet, and multimedia systems have experienced rapid growth, the dissemination of digital content through diverse communication channels has become effortless. However, this convenience has also led to an increased risk of illegal possession, duplication, manipulation, unauthorized usage, and distribution of digital information [16]. To mitigate these concerns during communications, information processing, and data storage, digital image watermarking has become a crucial research domain. This field enables researchers to establish a framework for safeguarding digital information by embedding imperceptible watermarks into digital images.

Within the field of digital image watermarking, significant focus has been directed toward investigating the utilization of transform domains, particularly the discrete cosine transforms (DCT) and the discrete wavelet transform (DWT). These transforms have demonstrated their essential role in effectively embedding imperceptible watermarks into digital images, facilitating the protection and verification of the content. Leveraging the properties of DCT and DWT, researchers can devise sophisticated watermarking techniques that elevate the security and integrity of digital information.

Numerous research studies have explored the application of the discrete cosine transform (DCT) and the discrete wavelet transform (DWT) in digital image watermarking. These transform domains have been widely adopted to bolster the security and resilience of watermarking techniques. Some prominent research studies that have utilized DCT and DWT include.

A blind watermarking technique for RGB color images is proposed by researchers Mohammed *et al*. [17], aiming to address copyright protection, identity theft, and privacy concerns in the Internet of Things (IoT) and artificial intelligence domain. The method involves selecting either the blue or green channel for embedding and applying DCT to non-overlapping square blocks of the chosen color. Subsequently, DWT decomposition is performed in the LH middle-frequency sub-band. To enhance security, the watermark image is encrypted. Experimental results demonstrate the high invisibility and robustness of the watermark.

Yuan *et al*. [18] present a robust medical watermarking algorithm designed to protect patients' privacy during medical data transmission. Their approach employs multilevel discrete wavelet transform (M-DWT), Daisy descriptor, and discrete cosine transform (DCT). The algorithm utilizes a three-level DWT, calculates the Daisy descriptor matrix from the center point of the low-frequency part, and applies DCT to generate a binary feature vector associated with the watermark. Encryption and zero watermark technology are employed for enhanced security. Simulation results show the algorithm's resilience against various attacks, achieving a balance between robustness and invisibility in medical image watermarking.

Devi and Mohapatra [19] introduce a novel blind medical image watermarking system tailored for CT scans, X-rays, MRIs, and ultrasound Dicom images. It employs a hybrid DWT-DCT-SVD scheme optimized via grey wolf optimization (GWO) to sequentially embed three binary watermark images into the cover image. DWT and DCT determine suitable hiding positions, and SVD transforms the DCT matrix into a singular matrix. GWO calculates the gain value for message bit insertion. Performance evaluation using PSNR and NCC metrics shows the method's superiority over existing systems, particularly in countering image processing attacks. Conversely, Hamami *et al*. [20] emphasize the importance of digital image protection in the digital age and propose innovative approaches that utilize wavelets and DCT for watermarking medical images. Their techniques strike a balance between imperceptibility and robustness, aiming to protect copyrights and address digitalization's security challenges.

Abadi and Moallem [21] propose a robust digital image watermarking technique that combines frequency and wavelet domains. Their algorithm selects the optimal color component and wavelet sub-band, implementing three parallel stages for embedding and extraction. The method transforms the color component into the wavelet domain, pre-processes it using Discrete Cosine Transformers, and embeds the watermark with a secret key. Watermark extraction employs rank detection and voting, exhibiting strong resistance against Gaussian noise attacks while preserving imperceptibility. Saighi and Chitroub [22] introduce a robust grayscale image watermarking method using discrete wavelet transform (DWT) and discrete cosine transform (DCT). Their approach partitions sub-matrices into blocks, applies 2D-DCT, and embeds watermark bits using pseudo-random sequences and scaling factors in specific DCT coefficients. Watermarked images are derived through inverse transforms, and watermark extraction utilizes correlations, with an Arnold transform applied for enhanced security.

Garg and Kishore [23] introduce an original blind watermarking technique that prioritizes robustness and imperceptibility through a frequency domain transform, incorporating artificial bee colony (ABC) optimization for secure watermarking with encrypted images. They employ a 2-level discrete wavelet transform (DWT) and discrete cosine transform (DCT) for embedding, resulting in high peak signal to noise ratio (PSNR) and normalized correlation (NC) values during evaluation. In a similar vein, Begum *et al*. [24] propose a hybrid blind watermarking system using DCT, DWT, and SVD to enhance secure multimedia sharing. Their method involves encrypted watermarking and successive transformations on both the watermark and host images, achieving improved robustness, imperceptibility, and security under various attacks compared to existing methods.

Gul *et al*. [25] introduce a unique blind robust color image watermarking technique for copyright protection, utilizing a grayscale watermark to enhance capacity. This method employs one-level discrete wavelet transform on the Cb color component and embeds scrambled watermark pixels into 4x4 discrete cosine transform (DCT) coefficients of the LL subband, using a division-based formula. Extraction employs a division-based extraction formula on the DCT coefficients, demonstrating robustness against attacks while maintaining imperceptibility in experimental evaluations. Zhou *et al*. [26] present an adaptive positioning document watermarking algorithm combining discrete wavelet transform (DWT) and discrete cosine transform (DCT) for copyright protection. They overcome challenges posed by limited color and texture information in document images by utilizing adaptive positioning, DWT, DCT, and other techniques, ensuring content independence, robustness against capture process attacks, and extraction accuracy, even with incomplete document images.

Koolwal *et al*. [27] introduce a novel watermarking technique integrating SVD, DCT, and DWT for enhanced image security and authentication. The method embeds the watermark image into the low-frequency DWT sub-band of the DCT of the cover image, utilizing optimization algorithms such as PSO and Jaya. Feature points are employed for watermark embedding, and image quality is assessed through parameters like PSNR, SSIM, and correlation coefficient. This scheme prioritizes image quality and security, effectively countering various attacks, and overcoming the limitations of traditional watermarking algorithms. Similarly, Yang *et al*. [28] present an image watermarking algorithm based on DWT and DCT to combat digital image piracy, which involves encrypting the binary watermark, applying the Arnold transform, performing wavelet transform decomposition, and embedding through modified DCT coefficients. Experimental results demonstrate good invisibility and robustness against attacks, providing practical protection for preserving digital image copyrights.

Hasan *et al*. [29] propose an encryption-based image watermarking scheme that combines second-level discrete wavelet transform (2DWT) and discrete cosine transform (DCT) with auto extraction. Their scheme demonstrates remarkable resilience against various image-processing attacks, achieving a perfect bit correction ratio (100%) and maintaining high-quality reconstructed images with a peak signal-to-noise ratio (PSNR) of ≥40 db and a structural similarity (SSIM) of ≥0.9. In distinct research, Zairi *et al*. [30] present a robust algorithm for digital image watermarking, utilizing a combination of 2-level discrete wavelet transform (DWT), discrete cosine transforms (DCT), and QR decomposition. Their algorithm exhibits strong imperceptibility and robustness against different attacks, making it an efficient and dependable solution for safeguarding intellectual properties.

Fares *et al*. [31] propose two innovative blind watermarking methods for secure medical images in telemedicine. The first approach combines DCT and Schur decomposition for discreet embedding, balancing robustness and imperceptibility. The second method uses DWT and Schur decomposition for comprehensive watermark distribution, fortifying resilience against attacks. Rigorous experiments confirm their effectiveness, preserving medical data privacy and instilling trust in telemedicine. Similarly, Hema *et al*. [32]

present a blind watermarking scheme using specific DWT-DCT coefficients and generalized Gaussian distributions. Their approach demonstrates optimal metrics, countering various attacks and endorsing its practical application in copyright protection.

Ernawan *et al*. [33] propose an adaptive scaling factor-based digital watermarking technique for image protection. Using selected DWT and DCT coefficients, they generate the adaptive scaling factor based on their relevance to the average value of DWT-DCT coefficients. The method achieves high PSNR (47db) and SSIM (0.987) values, showing resilience against various attacks. Similarly, Sripradha *et al*. [34] present a non-blind watermarking technique using DWT, DCT, and Schur decomposition for medical image authentication. The method is effective for X-ray and color images, offering robustness and imperceptibility, as confirmed through Matlab simulations considering different attacks.

Joseph *et al*. [35] propose an original digital watermarking technique combining DCT and DWT, achieving superior quality in watermarked images with higher PSNR and lower MSE values than existing methods. Souadek and Nasser [36] present a blind and robust watermarking algorithm using a hybrid combination of DWT and DCT with edge insertion, enhancing resilience against various attacks while preserving image quality. Both studies contribute to the advancement of digital watermarking, ensuring content protection, authenticity, and integrity.

Kavitha *et al*. [37] emphasize preserving digital data ownership using a neural network-based watermarking technique that creates and extracts a robust watermark independently from the original image, employing DCT and DWT for embedding a visible watermark. Abdulrahman and Ozturk [38] present a resilient color image watermarking method combining DCT and DWT, which processes RGB images into components and embeds a scrambled grayscale watermark into DWT bands while maintaining image transparency. Zhang *et al*. [39] focus on wavelet domain watermarking, using DWT and DCT, introducing advanced algorithms for optimized watermark extraction, particularly in denoised watermarked images, with experimental evaluations confirming their effectiveness.

Li *et al*. [40] introduce an advanced color holographic watermarking technique using the DCT-DWT algorithm, dividing images into RGB channels, generating watermarks with a four-step phase shift approach, and employing first-order wavelet decomposition for enhanced security. This approach extracts low-frequency components for precise DCT-based watermark embedding, offering high resilience to conventional attacks with an embedding strength of 0.1 and a PSNR value of 57.1769 dB, promising unparalleled protection for color holographic watermarks in carrier images. Luyen *et al*. [41] propose an asymmetric watermarking method using normal distribution-based public keys and intentionally permuted subsets for secret keys, embedded via DCT and DWT. Their approach showcases remarkable robustness with a PSNR value of 44.1226 and good watermarking quality exceeding 40 dB, surpassing related work in watermarking quality.

4. COMPARISON AND DISCUSSION

To provide a comprehensive review and comparative analysis of digital image watermarking techniques based on DCT and DWT, an examination of various approaches proposed in the literature has been conducted. The review aims to evaluate the strengths and analyze the performance of existing algorithms, identifying key challenges encountered in watermarking techniques, including attacks, synchronization, and robustness to image processing operations.

In Table 1 [41] (see appendix) a comprehensive overview of DCT and DWT-based watermarking schemes is presented, emphasizing key parameters crucial for comparative analysis. To facilitate a nuanced assessment, several essential factors such as robustness, imperceptibility, computational complexity, and capacity have been considered. These factors collectively shape the effectiveness, usability, and suitability of watermarking techniques for specific applications, striking a delicate balance between robustness, imperceptibility, computational efficiency, and data capacity [42]. The aim is to provide valuable insights into the intricate trade-offs involved in choosing between DCT and DWT for distinct watermarking requirements. By systematically evaluating these parameters, a foundation for decision-making is offered, enabling researchers and practitioners to make informed choices based on the unique demands of their applications [43]–[47] (see Appendix).

4.1. Analysis

The comparison initially outlines watermarking techniques for color and gray images, considering factors like robustness, imperceptibility, capacity, and PSNR. For color images, there is an emphasis on balancing these factors, though specific PSNR values are not provided. Gray images exhibit varying PSNR values, reflecting their image quality. Techniques with exceptionally high PSNR values exceeding 40 dB are suited for applications demanding fidelity, such as medical information security and image security. Conversely, those with moderate PSNR values around 30-35 dB prioritize robustness and capacity, making them suitable for scenarios where watermark invisibility is less critical, such as copyright protection. The choice of technique should align with specific application requirements, considering the balance between image quality, robustness, and imperceptibility.

By applying DWT and DCT in different ways, researchers obtain varying levels of robustness, imperceptibility, computational complexity, and capacity. Assessing these factors provides insights into each technique's performance. Robustness evaluation reveals how well these techniques withstand attacks while preserving embedded information [48], while imperceptibility assessment highlights their effectiveness in concealing watermarks [49]. Capacity evaluation determines their ability to embed larger amounts of data within watermarks, suitable for applications with higher data payloads.

Ultimately, the detailed comparison provides a concise summary of evaluated watermarking techniques, facilitating a comprehensive understanding of their performance characteristics. This resource is invaluable for researchers and practitioners in making informed decisions regarding the selection and implementation of DCT and DWT-based watermarking techniques.

4.2. Research gap finding

Based on the comprehensive reviews, it can be concluded that a significant research gap exists in the domain of digital image watermarking based on DCT and DWT. Specifically, there is a need to explore fusion techniques that effectively combine the strengths of both transforms to enhance the overall performance of watermarking systems. Additionally, the development of algorithms capable of withstanding common image processing operations while ensuring the visibility and integrity of the embedded watermark is crucial. Furthermore, further research should focus on tailoring watermarking techniques to suit specific applications or domains, taking into account the unique characteristics and requirements of each. Lastly, investigating factors such as embedding capacity, perceptual quality, and robustness would contribute to advancing the field of digital image watermarking and optimizing the trade-offs among these parameters.

5. CONCLUSION

This research article concludes that through a comprehensive review and comparative analysis of digital image watermarking techniques based on Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT), the objectives of the study have been successfully achieved. The strengths and limitations of each transform domain were examined, and the performance of existing algorithms was analyzed. Key challenges in watermarking techniques, such as attacks, synchronization, and robustness to image processing operations, were identified. The comparative analysis of DCT and DWT-based watermarking schemes provided insights into the trade-offs involved in choosing between the two transforms for specific requirements. The findings of this research enable researchers and practitioners to make informed decisions and gain deeper insights into the selection of the most suitable transform domain for their specific watermarking needs. Furthermore, this research highlights the current state-of-the-art, identifies research gaps, and emphasizes the need for further advancements in the field of digital image watermarking, with the aim of developing more effective and robust techniques.

ACKNOWLEDGEMENTS

We would like to acknowledge the support and assistance provided by my teachers who have offered their invaluable input, suggestions, and encouragement throughout this research. Your valuable discussions and constructive feedback have been immensely helpful.

APPENDIX

Table 1. Comparison of DCT and DWT-based watermarking techniques

Image type	Host image and watermark image size (pixel) respectively	Factors	Advantages	PSNR	Applications	Ref.
Color images	1024 x 1024, 64 x 64	Robustness, Imperceptibilit, Capacity	Trade-off between imperceptibility, robustness against AWGN attacks, and embedding capacity.	-	Copyright protection	[22]
Gray image	512 x 512, 32 x 32	Robustness, Imperceptibility	Robustness against most of the attacks.	> 40 db	Copyright protection	[23]

Table 1. Comparison of DCT and DWT-based watermarking techniques (*continue*)

Image type	Host image and watermark image size (pixel) respectively	Factors	Advantages	PSNR	Applications	Ref.
Gray image	512 x 512, 64 x 64	Robustness, Imperceptibility	Strive for better imperceptibility and enhanced robustness against filter, salt-and-pepper noise (SPN), and rotation attacks.	57.63 db	Copyright protection	[25]
Gray image	- 64 x 64	Invisibility, Robustness	Achieve a balance between watermark invisibility and robustness.	30.3 db	Copyright protection	[29]
Gray image	Different size	Robust Secure	Ensure robustness against diverse attacks and image enhancement processes, maintain high-quality reconstructed images, achieve extremely low bit rate error in extracted watermarks, and establish resistance to tampering with any image area.	> 40 db	Copyright protection, ownership verification, different cybersecurity applications	[30]
Gray image	512 x 512, 32 x 32	Robustness, Imperceptibility	Attain excellent imperceptibility while maintaining robustness against diverse attacks.	> 35 db	Security	[31]
Gray image	1024 x 1024, 32 x 32	Robustness, Imperceptibility	Ensure high-quality watermarked images while exhibiting strong resilience against various conventional attacks.	>47.98 db	Medical information security	[32]
Color images	512 x 512 -	Robustness, Imperceptibility	Demonstrate robustness against a wide range of image processing attacks while ensuring efficient performance.	-	Copyright protection	[33]
Gray image	512 x 512, 32 x 32	Robustness	Robustness against most of the attacks.	47 db	Copyright protection	[34]
Color images	3072 x 3072, 672 x 672	Robustness, Imperceptibility	Ensure both robustness and imperceptibility of the image against a multitude of attacks.	33 db	Image authentication	[35]
Color images	-	Quality	Improve the image quality after the watermarking process.	51.01 db	Image security	[36]
Gray image	512 x 512, 32 x 32	Robustness	High imperceptibility and good robustness against most attacks.	38.91 db	Copyright protection	[37]
Color images	1024x1024 x 3, 96 x 96	Robustness, Imperceptibilit, Transparency	Ensure robustness against diverse attacks, while preserving imperceptibility and transparency of the watermarked images.	> 35 db	Copyright protection	[39]
Gray image	256 x 256, 32 x 32	Robustness	Exhibit robustness against the majority of attacks.	45 db	Image copyright	[40]
Color images	2048 x 2048, 512 x 512	Robustness	Demonstrate strong resistance against conventional attacks while preserving important watermark features.	57.17 db	Copyright protection, ownership verification	[41]
Gray image	512 x 512, -	Robustness	Exhibit superior strength compared to related work against common signal processing techniques and geometric distortions, such as JPEG compression, cropping, Gaussian	44.12 db	Copyright protection	[42]
Gray image	512 x 512, 64 x 64	Robustness, Imperceptibility	Achieve significant improvements in robustness while effectively maintaining	> 42 db	Digital security of an image	[44]
Gray image	512 x 512, -	Robustness, Imperceptibility	The experimental results substantiate that our scheme offers outstanding robustness against various image attacks.	42 db	Copyright protection, ownership verification	[45]
Gray image	512 x 512, 32 x 32	Robustness, Imperceptibilit, Capacity	Exhibit robustness against a specific number of attacks while maintaining imperceptibility.	-	Secure the host image	[46]
Gray image	512 x 512, 256 x 256	Robustness, Imperceptibility	Attain superior performance in terms of both robustness and imperceptibility.	55.01 db	Digital security of an image	[47]
Gray image	512 x 512, 512 x 512	Robustness	Demonstrate robustness against a wide range of image-processing attacks.	34.87 db	Copyright protection	[48]

REFERENCES

[1] F. Ernawan and D. Ariatmanto, "A recent survey on image watermarking using scaling factor techniques for copyright protection," *Multimedia Tools and Applications*, vol. 82, no. 18, pp. 27123–27163, Jul. 2023, doi: 10.1007/s11042-023-14447-5.

[2] D. Yi, "Research on the Relevant Methods and Technologies of Digital Watermarking," *Highlights in Science, Engineering and Technology*, vol. 47, pp. 217–223, May 2023, doi: 10.54097/hset.v47i.8210.

[3] M. Begum and M. S. Uddin, "Notes on Image Watermarking and Steganography," in *Proceedings of International Conference on Information and Communication Technology for Development: ICICTD 2022*, 2023, pp. 1–14. doi: 10.1007/978-981-19-7528-8_1.

[4] H. Wang, Z. Yuan, S. Chen, and Q. Su, "Embedding color watermark image to color host image based on 2D-DCT," *Optik*, vol. 274, p. 170585, Mar. 2023, doi: 10.1016/j.ijleo.2023.170585.

[5] A. Hernández-Joaquín, G. Melendez-Melendez, and R. Cumplido, "A secure DWT-based dual watermarking scheme for image authentication and copyright protection," *Multimedia Tools and Applications*, vol. 82, no. 27, pp. 42739–42761, Nov. 2023, doi: 10.1007/s11042-023-14974-1.

[6] P. Aberna and L. Agilandeeswari, "Digital image and video watermarking: methodologies, attacks, applications, and future directions," *Multimedia Tools and Applications*, Jun. 2023, doi: 10.1007/s11042-023-15806-y.

[7] A. Ray and S. Roy, "Recent trends in image watermarking techniques for copyright protection: a survey," *International Journal of Multimedia Information Retrieval*, vol. 9, no. 4, pp. 249–270, Dec. 2020, doi: 10.1007/s13735-020-00197-9.

[8] W. Alomoush *et al.*, "Digital image watermarking using discrete cosine transformation based linear modulation," *Journal of Cloud Computing*, vol. 12, no. 1, 2023, doi: 10.1186/s13677-023-00468-w.

[9] P. A C and S. M T, "An Overview on Research Trends, Challenges, Applications and Future Direction in Digital Image Watermarking," *International Research Journal on Advanced Science Hub*, vol. 5, no. 01, pp. 8–14, Jan. 2023, doi: 10.47392/irjash.2023.002.

[10] M. Ali, "Robust Image Watermarking in Spatial Domain Utilizing Features Equivalent to SVD Transform," *Applied Sciences (Switzerland)*, vol. 13, no. 10, p. 6105, May 2023, doi: 10.3390/app13106105.

[11] K. B. Sk, D. Roja, D. Lavanya, A. S. Sk, and V. Tata, "The Efficient And Blind Digital Image Watermarking In Spatial Domain," *International Journal of Progressive Research in Engineering Management and Science (IJPREMS)*, vol. 3, pp. 13-19.

[12] F. L. Malallah, A. A. Jafaar, N. H. Abbas, and M. G. Saeed, "Reversible color video watermarking scheme based on hybrid of integer-to-integer wavelet transform and Arnold transform," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 4, p. 3519, Aug. 2020, doi: 10.11591/ijece.v10i4.pp3519-3527.

[13] D. Li *et al.*, "Hybrid Encrypted Watermarking Algorithm for Medical Images Based on DCT and Improved DarkNet53," *Electronics*, vol. 12, no. 7, p. 1554, Mar. 2023, doi: 10.3390/electronics12071554.

[14] S. Kashifa, S. Tangeda, U. K. Sree, and V. M. Manikandan, "Digital Image Watermarking and Its Applications: A Detailed Review," in *2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, Feb. 2023, pp. 1–7. doi: 10.1109/SCEECS57921.2023.10063033.

[15] L. Novamizanti, G. Budiman, and E. Nur Fitri Astuti, "Robust audio watermarking based on transform domain and SVD with compressive sampling framework," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 18, no. 2, p. 1079, Apr. 2020, doi: 10.12928/telkomnika.v18i2.14773.

[16] A. Tiwari, D. Awasthi, and V. K. Srivastava, "Image security enhancement to medical images by RDWT-DCT-Schur decomposition-based watermarking and its authentication using BRISK features," *Multimedia Tools and Applications*, Jun. 2023, doi: 10.1007/s11042-023-15878-w.

[17] A. O. Mohammed, H. I. Hussein, R. J. Mstafa, and A. M. Abdulazeez, "A blind and robust color image watermarking scheme based on DCT and DWT domains," *Multimedia Tools and Applications*, vol. 82, no. 21, pp. 32855–32881, Sep. 2023, doi: 10.1007/s11042-023-14797-0.

[18] Y. Yuan, J. Li, J. Liu, U. A. Bhatti, and Y.-W. Chen, "A Robust Watermarking Algorithm for Medical Images Based on DWT-Daisy and Discrete Cosine Transform," 2023, pp. 205–214. doi: 10.1007/978-981-99-3311-2_18.

[19] H. S. Devi and H. Mohapatra, "A novel robust blind medical image watermarking using GWO optimized DWT-DCT-SVD," *Multimedia Tools and Applications*, vol. 82, no. 26, pp. 41267–41286, Nov. 2023, doi: 10.1007/s11042-023-15158-7.

[20] R. Hamami, N. Zermi, L. Boubchir, and A. Khaldi, "Wavelets and DCT Watermarking for Medical Image," in *2022 Ninth International Conference on Software Defined Systems (SDS)*, Dec. 2022, pp. 1–3. doi: 10.1109/SDS57574.2022.10062946.

[21] R. Y. Abadi and P. Moallem, "Robust and optimum color image watermarking method based on a combination of DWT and DCT," *Optik*, vol. 261, p. 169146, Jul. 2022, doi: 10.1016/j.ijleo.2022.169146.

[22] A. Saighi and S. Chitroub, "Robust grayscale image watermarking approach using DCT and DWT," in *2022 15th International Conference on Security of Information and Networks (SIN)*, Nov. 2022, pp. 01–06. doi: 10.1109/SIN56466.2022.9970493.

[23] P. Garg and R. R. Kishore, "An efficient and secured blind image watermarking using ABC optimization in DWT and DCT domain," *Multimedia Tools and Applications*, vol. 81, no. 26, pp. 36947–36964, Nov. 2022, doi: 10.1007/s11042-021-11237-9.

[24] 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.

[25] E. Gul, "A blind robust color image watermarking method based on discrete wavelet transform and discrete cosine transform using grayscale watermark image," *Concurrency and Computation: Practice and Experience*, vol. 34, no. 22, Oct. 2022, doi: 10.1002/cpe.6884.

[26] Y. Zhou, L. Hong, and X. Zhu, "Document Image Watermarking Scheme with Adaptive Positioning Based on Discrete Wavelet Transform and Discrete Cosine Transform," in *2022 IEEE 24th International Workshop on Multimedia Signal Processing (MMSP)*, Sep. 2022, pp. 1–6. doi: 10.1109/MMSP55362.2022.9949580.

[27] P. Koolwal and S. Sharma, "Performance Improvement of Optimization Algorithm for Digital Image Watermarking in Hybrid DWT-DCT Transform," in *2022 International Conference on Electronics and Renewable Systems (ICEARS)*, Mar. 2022, pp. 1001–1005. doi: 10.1109/ICEARS53579.2022.9752306.

[28] S. Yang, D. Sun, F. You, and J. Dong, "Robust image watermarking algorithm based on DWT and DCT," in *International Conference on Network Communication and Information Security (ICNCIS 2022)*, Nov. 2022, p. 4. doi: 10.1117/12.2657074.

[29] N. Hasan, M. S. Islam, W. Chen, M. A. Kabir, and S. Al-Ahmadi, "Encryption Based Image Watermarking Algorithm in 2DWT-DCT Domains," *Sensors*, vol. 21, no. 16, p. 5540, Aug. 2021, doi: 10.3390/s21165540.

[30] M. Zairi, T. Boujiha, and O. Abdelhaq, "An Algorithm for Digital Image Watermarking using 2-Level DWT, DCT and QR Decomposition based on Optimal Blocks Selection," in *Proceedings of the 3rd International Conference on Networking, Information Systems & Security*, Mar. 2020, pp. 1–4. doi: 10.1145/3386723.3387863.
[31] K. Fares, A. Khaldi, K. Redouane, and E. Salah, "DCT & DWT based watermarking scheme for medical information security," *Biomedical Signal Processing and Control*, vol. 66, p. 102403, Apr. 2021, doi: 10.1016/j.bspc.2020.102403.
[32] M. Hema, S. P. Shyry, and R. Scholar, "An Improved Hybrid DCT-DWT Blind Watermarking Technique for Securing Multimedia Images," 2022, doi: 10.21203/rs.3.rs-1352507/v1.
[33] F. Ernawan, D. Ariatmanto, and A. Firdaus, "An Improved Image Watermarking by Modifying Selected DWT-DCT Coefficients," *IEEE Access*, vol. 9, pp. 45474–45485, 2021, doi: 10.1109/ACCESS.2021.3067245.
[34] R. Sripradha and K. Deepa, "Robust and Imperceptible Digital Image Watermarking Based on DWT-DCT-Schur," in *Communications in Computer and Information Science*, vol. 1365, 2021, pp. 337–351. doi: 10.1007/978-981-16-0425-6_25.
[35] H. Joseph and B. K. Rajan, "Image Security Enhancement using DCT & DWT Watermarking Technique," in *2020 International Conference on Communication and Signal Processing (ICCSP)*, Jul. 2020, pp. 0940–0945. doi: 10.1109/ICCSP48568.2020.9182052.
[36] R. Souadek and G. Nasser, "Blind and robust image watermarking algorithm Based on DWT-DCT and Edge Insertion," 2023, doi: N. Blind and robust image watermarking algorithm Based on DWT-DCT and Edge Insertion.
[37] R. S. Kavitha, U. Eranna, and M. N. Giriprasad, "DCT-DWT Based Digital Watermarking and Extraction using Neural Networks," in *2020 International Conference on Artificial Intelligence and Signal Processing (AISP)*, Jan. 2020, pp. 1–5. doi: 10.1109/AISP48273.2020.9073104.
[38] A. K. Abdulrahman and S. Ozturk, "A novel hybrid DCT and DWT based robust watermarking algorithm for color images," *Multimedia Tools and Applications*, vol. 78, no. 12, pp. 17027–17049, Jun. 2019, doi: 10.1007/s11042-018-7085-z.
[39] Y. Zhang, Y. Li, and Y. Sun, "Digital Watermarking Based on Joint DWT–DCT and OMP Reconstruction," *Circuits, Systems, and Signal Processing*, vol. 38, no. 11, pp. 5135–5148, Nov. 2019, doi: 10.1007/s00034-019-01112-2.
[40] S. K. Li *et al.*, "Research on Robust Algorithm of Color Holographic Watermark Based on DCT-DWT," *IOP Conference Series: Materials Science and Engineering*, vol. 563, no. 5, p. 052015, Jul. 2019, doi: 10.1088/1757-899X/563/5/052015.
[41] C. T. Luyen, N. H. Cuong, and P. Van At, "A Novel Public Key Robust Watermarking Method for Still Images Based on Intentional Permutation Based on DCT and DWT," in *2019 IEEE-RIVF International Conference on Computing and Communication Technologies (RIVF)*, Mar. 2019, pp. 1–5. doi: 10.1109/RIVF.2019.8713679.
[42] A. Saha, S. S. Roy, A. Basu, and A. Chattopadhyay, "A Study on Statistical Analysis for Performance Evaluation of Digital Watermarking," in *2023 Third International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT)*, Jan. 2023, pp. 1–4. doi: 10.1109/ICAECT57570.2023.10117928.
[43] H.-T. Hu and L.-Y. Hsu, "Collective blind image watermarking in DWT-DCT domain with adaptive embedding strength governed by quality metrics," *Multimedia Tools and Applications*, vol. 76, no. 5, pp. 6575–6594, Mar. 2017, doi: 10.1007/s11042-016-3332-3.
[44] A. Benoraira, K. Benmahammed, and N. Boucenna, "Blind image watermarking technique based on differential embedding in DWT and DCT domains," *EURASIP Journal on Advances in Signal Processing*, vol. 2015, no. 1, p. 55, Dec. 2015, doi: 10.1186/s13634-015-0239-5.
[45] R. K. Arya, S. Singh, and R. Saharan, "A secure non-blind block based digital image watermarking technique using DWT and DCT," in *2015 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, Aug. 2015, pp. 2042–2048. doi: 10.1109/ICACCI.2015.7275917.
[46] A. K. Singh, M. Dave, and A. Mohan, "Hybrid Technique for Robust and Imperceptible Image Watermarking in DWT–DCT–SVD Domain," *National Academy Science Letters*, vol. 37, no. 4, pp. 351–358, Aug. 2014, doi: 10.1007/s40009-014-0241-8.
[47] B. RAM, "Digital Image Watermarking Technique Using Discrete Wavelet Transform and Discrete Cosine Transform," *SSRN Electronic Journal*, 2022, doi: 10.2139/ssrn.4173742.
[48] S. N. V. J. D. Kosuru, A. Pradhan, A. R. Gottimukkala, and G. Swain, "Efficiency Evaluation Parameters of Digital Image Watermarking Techniques," in *2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS)*, Mar. 2023, pp. 1077–1082. doi: 10.1109/ICACCS57279.2023.10113036.
[49] S. A. Barlaskar, A. M. Kirupakaran, N. Ahmad, K. S. Yadav, T. Khan, and R. H. Laskar, "Imperceptibility and robustness study in different transform domain for copyright protection in digital image watermarking in hybrid SVD-domain," in *2023 3rd International conference on Artificial Intelligence and Signal Processing (AISP)*, Mar. 2023, pp. 1–5. doi: 10.1109/AISP57993.2023.10135001.

BIOGRAPHIES OF AUTHORS

Md. Apu Hosen is a Master's student pursuing Computer Science and Engineering at Jashore University of Science and Technology, Bangladesh. He holds a Bachelor's degree in Computer Science and Engineering from the same university. Presently, he works as a Lecturer of Computer Science and Engineering at Northern University of Business and Technology Khulna, Bangladesh. His research interests encompass machine learning, deep learning, computer vision, explainable AI, and networking. He can be contacted at apu.cse.just@gmail.com.

Shahadat Hoshen Moz is a MSc Student of Computer Science and Engineering, Jashore University of Science and Technology, Bangladesh. He received the B.Sc. degree in Computer Science and Engineering from Jashore University of Science and Technology. Currently he works as a Lecturer of Computer Science and Engineering at Northern University of Business and Technology Khulna, Bangladesh. His research interests include machine learning, deep learning, computer vision, explainable AI, and networking. He can be contacted at shahadat.cse.just@gmail.com.

Sk. Shalauddin Kabir is a Lecturer in the department of Computer Science and Engineering (CSE) at Jashore University of Science and Technology (JUST), Bangladesh. Before joining at JUST, he was working as a Lecturer in the department of Computer Science and Engineering (CSE) at Northern University of Business and Technology Khulna (NUBTK), Khulna, Bangladesh. He received B.Sc. (Engg.) and M.Sc. (Engg.) in Computer Science and Engineering (CSE) from Jashore University of Science and Technology (JUST), Bangladesh. His research interest includes machine learning, image processing, AI, SDN and IoT. He can be contacted at sks.kabir@just.edu.bd.

Md. Nasim Adnan received BSc in Computer Science and Engineering (CSE) from Khulna University, Bangladesh. MSc in CSE from Bangladesh University of Engineering and Technology (BUET) and PhD from Charles Sturt University (Australia) in 2002, 2010 and 2017 respectively. Previously he worked as an Assistant Professor in University of Liberal Arts Bangladesh (ULAB). He also served as a Systems Analyst in Bangladesh Bank (The Central Bank of Bangladesh). Currently he works as a Assistant Professor in the department of Computer Science and Engineering (CSE) at Jashore University of Science and Technology (JUST), Bangladesh. His research interest includes Data Mining, Software Engineering, and E-Commerce. For any inquiries, he can be reached at nasim.adnan@just.edu.bd.

Syed Md. Galib is a Professor in the department of Computer Science and Engineering (CSE) at Jashore University of Science and Technology (JUST), Bangladesh. Before joining at JUST, he was working as an Associate Professor in the department of Computer Science and Information Technology at Patuakhali Science and Technology University, Bangladesh. He finished his PhD from Swinburne University of Technology, Australia in 2015. Before that, he completed his M.Sc. in Computer Engineering from Dalarna University, Sweden in 2008. He obtained his B.Sc. in Computer Science and Engineering from Khulna University, Bangladesh in 2005. Currently Dr. Galib is the chairman of the department of CSE, JUST. Moreover, he leads a research group named Artificial Intelligence for Development (AID group) within the department of CSE. His research interest is mostly in the field of image processing and artificial intelligence applied to social development. He can be contacted at galib.cse@just.edu.bd.