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All phase discrete cosine biorthogonal transform versus discrete cosine transform in digital watermarking

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Abstract

The field of digital image watermarking has collected considerable attention from researchers and scholars, that eventually presents interesting challenges and opportunities for technological advancements. We can successfully address issues with multimedia access control by utilizing technological advancements, such as transform domain techniques, steganography, multimedia synchronization, robust watermark extraction, and many. This can be used to enhance technology in many ways like intellectual property protection, data integrity and security, and others. Photographic Image Watermarking is the process of inserting a message as a watermark to host image in some multimedia format. We can try to restrict multimedia from unwanted access through the help of digital watermarking. A few elements such as capacity, security, imperceptibility, and robustness must be considered while creating an effective and productive digital watermarked image. This paper compares All Phase Discrete Cosine Biorthogonal Transform (APDCBT) and Discrete Cosine Transform (DCT) in the field of image authentication and Digital Watermarking. Our proposed system uses a PN – Sequence algorithm and a secret user key called K to generate random vectors for selected coefficients to increase the security and robustness. The above two algorithms are combined with commonly used algorithms like Discrete Wavelet Transform (DWT) and Singular Value Decomposition (SVD) for effective Digital Watermarking. For evaluating the imperceptibility of Watermarked Image, Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) are taken into consideration.

Keywords Image processing · Image watermarking · PN – Sequence · Robustness · Capacity · Imperceptibility · Security

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1 Introduction

The advancement of multimedia technologies has made various types of digital media readily available online in the form of web pages and public forums. However, the nature of digital media allows anyone to copy and distribute it without permission from the original author, which poses a challenge to ownership rights and copyright disputes. Digital watermarking is an innovative method that can help to resolve these issues by embedding an invisible message in multimedia documents, such as the author's copyright information or license details. This message can be extracted using specific algorithms and a secret key to identify the author's copy from a group of duplicates. In recent years, digital watermarking has become increasingly popular among multinational companies to avoid copyright disputes and claim ownership rights. It ensures content authentication, integrity verification, and produces protected high-quality images.

Watermarks can be embedded using a variety of techniques, such as spatial, transform, and hybrid domains. While transform domain methods alter transform coefficients, spatial domain methods alter the watermark's pixel values. Spatial domain methods have almost completely been replaced by transform domain techniques like DFT, DWT, and DCT in recent years. To maintain a balance between capacity, robustness, imperceptibility, and security, hybrid methods combine two or more algorithms. For applying digital watermarking, these elements are crucial. The performance of DCT and APDCBT when combined with DWT and SVD in each case is compared and examined in this paper. The imperceptibility is calculated using the MSE and PSNR. The paper offers a comparative analysis of hybrid methods, difficulties, problems with the research, and recommendations for upcoming researchers.

2 Related work

Z. Hou et al. [12] showed the All Phase Biorthogonal Transform (APBT) [33] and dual biorthogonal basis vectors as novel concepts in the research paper. Three types of APBT on the basis of the Walsh transform (WT), DCT, and IDCT are developed considering all phase digital filtering theory. The APBT matrices in accordance with DCT, IDCT, and WT are inferred, and they can be used to compress images other than DCT. The time complexity is reduced and hardware implementation is simplified because there is a reduction in the quantization table. Additionally, the suggested algorithm performs well even at low bit rates. Blocking artefacts, however, are generated when images are compressed at extremely low bit rates. Utilising post-processing techniques can lead to improved performance.

X. Zhou et al. [34] proposed that the digital watermarking has emerged as an effective option to claim the rights of ownership. A very resilient and hybrid watermarking approach is proposed in the study. To insert and retrieve the watermark, this approach uses the DWT and APDCBT which was published then. The Direct Current coefficients following block-based APDCBT in LH and HL frequency bands are changed by applying the watermark image to improve imperceptibility. The watermarked pictures created by the suggested method exhibit greater image quality than the standard watermarking method (through SVD) and other ways. Furthermore, experimental comparisons show that the proposed scheme has less of an impact on the original image and is more resistant to common signal processing attacks than other approaches. However, this paper's false-unsolved test applies to the proposed scheme.

K. Navas et al. [16] stated watermarking in the frequency domain using SVD has been documented in some cases. DCT-SVD and DWTSVD are the two most often adopted approaches. Traditional watermarking approaches have drawbacks, such as the inability to survive attacks (like gaussian noise), which are not present in algorithms using SVD. It provides a reliable watermarking solution with minimal or almost negligible distortion. Compression is provided using DCT-based watermarking methods, while scalability is provided by DWT-based compression. As a result, a new durable watermarking approach may be created by combining all three desirable qualities. They presented a non-blind transform domain watermarking approach applying DWT+DCT+SVD. The watermarking information is hidden using the DCT coefficients of the DWT coefficients. Even when applying attacks, this type of watermarking has been proven to be durable, and the visual watermark may be recovered with just a minimal degree of distortion.

The extension of the former mentioned work was done by A. Singh et al. [23]. A digital watermarking approach in accordance with DCT, SVD, and DWT is proposed in this study. The host picture is broken into 1-level DWT throughout the embedding process. SVD and DCT are used to transform the watermarked image. The host image's S component contains the S vector containing watermark information. The watermarked picture is created using the updated S vector, unchanged U and unchanged V vectors. Later, IDCT and IDWT must be applied. This methodology has been extensively verified against several known attacks, and it proved to perform better in terms of imperceptibility and robustness than current methods offered by other authors.

S. Bharati et al. [4] made a comparative analysis by combination of four watermarking techniques, namely: DWT, Bacterial Foraging Optimization (BFO), DCT, and Parallel Bacterial Foraging Optimization PBFO. Here the study emphasises on the importance of watermarking medical images. Because image processing is becoming increasingly significant in most of the medical domains. As a result, watermarking is becoming increasingly vital to offer picture security. For the goal of watermarking a medical picture, DWT, BFO, DCT, and Particle Swarm Optimization (PSO) were employed and are examined in this research. The Normalised Cross Correlation (NCC), PSNR, and Image Fidelity (IF) values were obtained for comparing purposes. By applying DWT on the image, they got 23.43 PSNR; however, by applying DWT+DCT+PBFO they got better result; i.e. 54.34 PSNR.

K. Handito et al. [10] demonstrated a comparison of the DCT+SVD and DWT+SVD digital image watermarking approaches. When watermarking digital data, particularly images, absolute invisibility is achieved when the image is put into a carrier image. The quality of the carrier picture will not be impacted by the attack, and neither will the inserted image. Watermarking on digital images will be implemented in this study utilising SVD with concentration on DCT and DWT with the expectation of good watermarking performance. In this scenario, there is a balance between picture watermarking invisibility and robustness. Low-frequency embedding watermarks are resistant to JPEG compression and Gaussian blur attack, whereas high-frequency embedding watermarks are resistant to Gaussian noise.

P. Gupta et al. [7] stated that Digital picture watermarking is a system designed to safeguard secret digital photographs from unauthorized copying and alteration. For high imperceptibility and robustness, a combination of Integer Wavelet Transform (IWT) and SVD was applied. Other aim is to compare the proficiency of the IWT+SVD method with the DWT+SVD approach at various scaling factors. The experimental findings for both methodologies have been presented, and several assessment criteria such as NCC and PSNR were computed. However, according to experimental findings, the scaling factor is the only factor that affects the watermark quality of both the watermarked image and the extracted watermark. Additionally, it has been noted that IWT-SVD requires less computation time than DWT-SVD.

N. Thakkar et al. [26] illustrate that a blind image watermarking approach using DWT and SVD. DWT is used on a medical image's ROI (region of interest) to obtain distinct frequency sub-bands. Block SVD is used on the ROI's LL to generate various singular matrices. The left singular value matrix of these selected blocks identifies a pair of elements with comparable values. To insert a piece of watermark material, the pair values are adjusted using a specific threshold. A watermark picture and a text watermark were used to authenticate and identify the original medical image. For identification, the watermark picture serves as authentication, while the text data comprises an electronic patient record (EPR). Additionally, the proposed blind watermarking scheme is efficient and robust for medical images. Performance surpasses existing schemes under various common image processing attacks.

3 Frequency domain watermarking techniques

3.1 Discrete cosine transform (DCT)

DCT aids in the separation of image into spectral sub-bands with varying degrees of relevance in terms of image quality [24]. DCT [20] is used to convert an image from the spatial domain to the frequency domain [8]. Two-dimension DCT known as DCT-II is simply referred to as DCT is mostly used.

The general equation of 2-D DCT is defined as,

$$\boldsymbol{F(x,y)} = \left(\frac{\boldsymbol{2}}{\boldsymbol{N}}\right)^{\frac{1}{2}}\left(\frac{\boldsymbol{2}}{\boldsymbol{M}}\right)^{\frac{1}{2}}\boldsymbol{A(x).A(y)}\sum_{c=0}^{N-1}\sum_{d=0}^{M-1}\cos\left[\frac{\boldsymbol{\pi.x}}{\boldsymbol{2.N}}(\boldsymbol{2c+1})\right].\cos\left[\frac{\boldsymbol{\pi.y}}{\boldsymbol{2.M}}(\boldsymbol{2d+1})\right].\boldsymbol{P(c,d)} \tag{1}$$

and the formula for 2-D inverse DCT is defined as,

$$\boldsymbol{F(x,y)} = \left(\frac{\boldsymbol{2}}{\boldsymbol{N}}\right)^{\frac{1}{2}}\left(\frac{\boldsymbol{2}}{\boldsymbol{M}}\right)^{\frac{1}{2}}\sum_{c=0}^{N-1}\sum_{d=0}^{M-1}\boldsymbol{A(c).A(d)}.\cos\left[\frac{\boldsymbol{\pi.c}}{\boldsymbol{2.N}}(\boldsymbol{2x+1})\right].\cos\left[\frac{\boldsymbol{\pi.d}}{\boldsymbol{2.M}}(\boldsymbol{2y+1})\right].\boldsymbol{P(c,d)} \tag{2}$$

Here,

(N, M)	(Rows, Columns) in Matrix
P (c, d)	Pixel intensity in each row and column
A(c or d)	$\begin{cases} \frac{1}{\sqrt{2}}, & c\ or\ d = 0 \\ 1, & otherwise \end{cases}$

3.2 Discrete wavelet transform (DWT)

The discrete interval sampling technique, DWT, is used to sample wavelets. It provides the information of spatial and frequency domains simultaneously [22]. DWT is made up of a low pass filter that collects the image's approximation information and a high pass filter that collects features like edges. Two one-dimensional DWTs are performed to get the two-dimension transform. The low-frequency (LF) information in a one-dimension transform is in the approximation coefficient, while the high-frequency (HF) information is in the detail coefficient.

Using two-dimensional DWT, the picture is further split into four sub-bands.

- LL or cA- LF in the horizontal (H) and vertical (V) direction.
- LH or cH - LF in the H and HF in the V direction.
- HL or cV - LH in the H and LF in the V direction.
- HH or cD - HF in the H and V direction.

The equation of image k after applying one-level DWT with its sub-bands is as follows,

$$K = \boldsymbol{K}_{\boldsymbol{LL}}^{\boldsymbol{1}} + \left(\boldsymbol{K}_{\boldsymbol{LH}}^{\boldsymbol{1}} + \boldsymbol{K}_{\boldsymbol{HL}}^{\boldsymbol{1}} + \boldsymbol{K}_{\boldsymbol{HH}}^{\boldsymbol{1}}\right) \tag{3}$$

where, K_{LL}^{1} represents the image approximation and K_{LH}^{1}, K_{HL}^{1}, and K_{HH}^{1} exemplify H, V and diagonal values of details, respectively. We can apply DWT repeatedly on the LL sub-band and can obtain multiple levels of DWT, splitting the image into multiple sub-bands, as shown in Eq. (4).

$$K = \boldsymbol{K}_{\boldsymbol{LL}}^{\boldsymbol{N}} + \sum\nolimits_{\boldsymbol{i=1}}^{\boldsymbol{N}} \left(\boldsymbol{K}_{\boldsymbol{LH}}^{\boldsymbol{i}} + \boldsymbol{K}_{\boldsymbol{HL}}^{\boldsymbol{i}} + \boldsymbol{K}_{\boldsymbol{HH}}^{\boldsymbol{i}}\right) \tag{4}$$

In our research paper, we have gone up to n = 2, i.e., two-level DWT.

3.3 All phase discrete cosine biorthogonal transform (APDCBT)

There is a common belief that DCT is better for energy concentration. Because of which it has broad acceptance and is used almost everywhere in image compression and watermark techniques. Despite that, as research expanded, it was found that DCT compressed images have block-like artefacts at lower bit rates. Keeping that in mind, a new transformation algorithm called APDCBT was introduced [25]. [12] compares DCT to APDCBT and concludes that APDBCT outperforms DCT in HF attenuation and LF aggregation. [3, 14, 28, 30] APDCBT was used in the field of information concealment, where it was used to replace DCT in order to improve robustness while watermarking. To understand APDCBT even better, we are comparing various watermarking techniques using DCT and APDCBT.

In APDCBT [3, 13, 34], a transformation matrix S with a dimension of N×N is defined as,

$$S\left(c,d\right) = \begin{cases} \frac{\boldsymbol{N-c}}{\boldsymbol{N^2}}, \boldsymbol{c} = \boldsymbol{0}, \ldots, \boldsymbol{N-1}, \ \boldsymbol{d} = \boldsymbol{0} \\ \frac{\boldsymbol{1}}{\boldsymbol{N^2}}\left[(\boldsymbol{N}-\boldsymbol{c}).\cos\left(\frac{\boldsymbol{cd\pi}}{\boldsymbol{N}}\right).\csc\frac{\boldsymbol{c\pi}}{\boldsymbol{N}}.\sin\frac{\boldsymbol{cd\pi}}{\boldsymbol{N}}\right], \\ \boldsymbol{c} = \boldsymbol{0}, \ldots, \boldsymbol{N-1}, \boldsymbol{d} = \boldsymbol{1}, \ldots, \boldsymbol{N-1} \end{cases} \tag{5}$$

and the inverse of APDCBT is defined as,

$$S\left(c,d\right) = \begin{cases} \frac{\boldsymbol{1}}{\boldsymbol{N}}, \ \boldsymbol{d} = \boldsymbol{0}, \ldots, \boldsymbol{N-1}, \ \boldsymbol{c} = \boldsymbol{0} \\ \frac{\boldsymbol{N-c+\sqrt{2}-1}}{\boldsymbol{N^2}}\left[\cos\left(\frac{\boldsymbol{c(2d+1)\pi}}{\boldsymbol{2N}}\right)\right], \\ \boldsymbol{d} = \boldsymbol{0}, \ldots, \boldsymbol{N-1}, \ \boldsymbol{c} = \boldsymbol{1}, \ldots, \boldsymbol{N-1} \end{cases} \tag{6}$$

3.4 Singular value decomposition (SVD)

SVD [7, 29] is a process of breaking down the matrix, say *M*, into a form of Eq. (7). This allows us to obtain the required singular values for the image while ignoring the non-essential values, thereby preserving the image's quality.

$$M = U * \sum * V^T \tag{7}$$

Here,

U	m×m matrix with orthonormal column
$\sum$	m×n matrix with singular values on the main diagonal
V	n×n matrix with orthonormal column
V^T	Transpose of matrix V

4 Performance metrics

Essentially, performance metrics are used to assess image quality by comparing it to the original image. We used MSE and PSNR in this paper, but there are many other methods.

4.1 Mean square error (MSE)

It is used to compare the quality of compressed image. It represents the sum of the squared errors between the compressed and original images. Over the entire image, it represents the average difference of the pixels. As the value of MSE decreases, the better image gets. Thus, better the image reconstructed. The following is its interpretation:

$$\boldsymbol{MSE} = \frac{\mathbf{1}}{\boldsymbol{p}.\boldsymbol{q}} \sum_{c=0}^{p-1} \sum_{d=0}^{q-1} [\boldsymbol{G}(\boldsymbol{c},\boldsymbol{d}) - \boldsymbol{H}(\boldsymbol{c},\boldsymbol{d})]^{\mathbf{2}} \tag{8}$$

Here,
(p, q) = rows and columns of the image
G (c, d) = Enhanced Image
H (c, d) = Original Image

4.2 Peak signal to noise ratio (PSNR)

PSNR is defined as the ratio of the maximum possible value of a signal to the power of distorting noise that affects image quality. It is commonly used to quantify image reconstruction quality and Lossy Compression. Decibels (dB) are used to measure it [5]. The higher the PSNR, the better the image reconstruction quality. It is defined as follows:

$$PSNR = 20log_{\mathbf{10}}\left(\boldsymbol{MX_p}\right) - \mathbf{10}log_{\mathbf{10}}(\boldsymbol{MSE}) \tag{9}$$

Here,
MX_p = Maximum possible pixel value of the image

Fig. 1 Comparison of DCT and APDCBT

5 Methodology

Here we are mainly comparing which is a better choice over DCT and APDCBT while applying it through various hybrid frequency techniques. So, there are four comparisons made which are in Figs. 1, 2, and 3.

5.1 1-Level DWT+DCT & 1-Level DWT+APDCBT

Figure 4 depicts the steps for embedding and extracting the watermark image from the cover image [4]. So, for 1-Level DWT, we apply it to the host image to 4 sub-bands. Now, the generated PN-sequence is used to embed the watermark image in LH and HL [19]. Here, DCT or APDCBT is applied to each 8*8 block of the LH and HL sub-band. Lastly, inverse DCT or inverse APDCBT on each block is done. Once inverse DWT is applied, we get watermarked image.

Fig. 2 Host image

Fig. 3 Watermark image

From Figs. 5 and 6, we can compare the quality of watermarked images because MSE and PSNR are used. It is evident that when we embed the watermark through DCT [9, 18], we get better imperceptible over APDCBT. As the Gain Factor (K) increases, the imperceptibility gets almost similar.

5.2 2-Level DWT+DCT & 2-Level DWT+APDCBT

Now, in the case of Level-2 DWT, we are applying it on the LL sub-band of the Level-1 DWT on Host Image. Hence, we get LL2, LH2, HL2 and HH2 sub-bands from it. After that, the PN-sequence is used to insert the message vector (or the watermark image) to the LH2 and HL2 sub-band. Figure 4 shows how the embedding and extraction are done of the watermarked image.

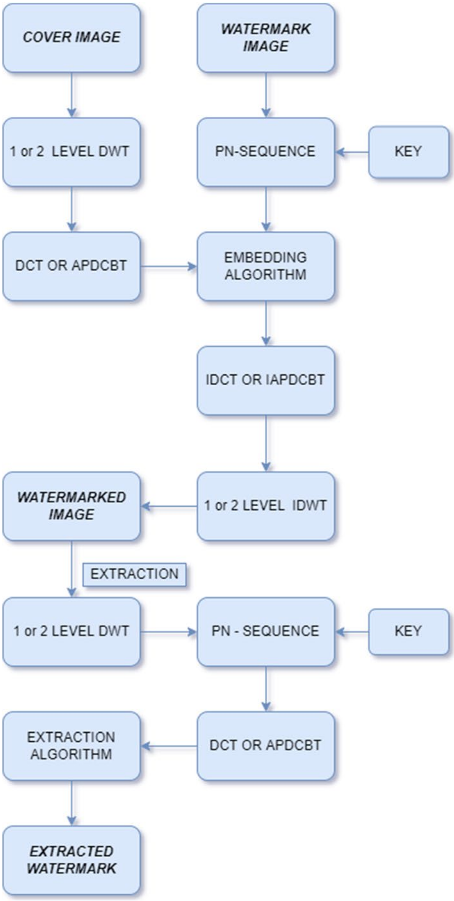
It is observed from Figs. 7 and 8 that Level-2 DWT is better than Level-1 DWT for this algorithm. Also, DCT has given much more clear images for all values of Gain Factor (K) than APDCBT.

5.3 1-Level DWT+DCT+SVD & 1-Level DWT+APDCBT+SVD

From Fig. 9, we can find the steps to fit the watermark image in the original image. [10, 11, 32] SVD is applied after we perform [2, 26] 1-level DWT and DCT on the HH sub-band (diagonal sub-band) [6]. The same is followed when APDCBT is applied [21]. Later, in the embedding algorithm, the inverse of DCT or APDCBT and inverse of DWT is performed to yield a watermarked image.

It is shown in [31, 34] that APDCBT is better than DCT when SVD is used to hide the information. Through performance measures (PSNR and MSE), it is conspicuous that APDCBT gave a better-quality image for different values of scale factor (K). Refer to Figs. 10 and 11 for the result.

Fig. 4 (1 or 2-Level DWT)+(DCT or APDCBT)



5.4 2-Level DWT+DCT+SVD & 2-Level DWT+APDCBT+SVD (proposed algorithm)

Here, [1] the same process is followed as the above method, but we are applying the 2-level DWT on the Cover Image such that we get (LL1, LH1, HL1, HH1) and using HH1 for the next level DWT we get (LL2, LH2, HL2, HH2). Now, the HH2 is divided into 8*8 blocks, such that we can perform APDCBT or DCT. Later, SVD is applied in the embedding algorithm to get the result. The following steps illustrate the embedding and extraction algorithm of the proposed method:

Embedding Algorithm:

Variables used:

- CI = Cover Image (let, it be of 512*512 size)
- WI = Watermark Image (let, it be of 128*128 size)
- $Final$ = Watermarked Image
- RW = Retrieved Watermark
- K = Scale Factor
- $LL2, LH2, HL2, HH2$ = Sub-bands of HH

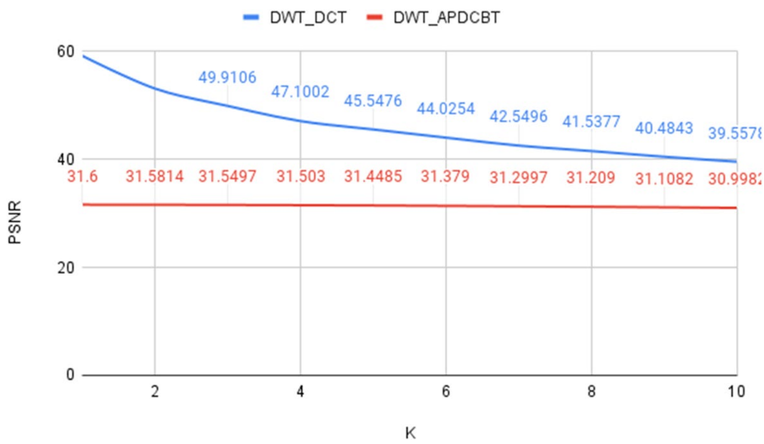


Fig. 5 PSNR of Level−1 DWT+DCT and Level-1 DWT+APDCBT

- *New_HH* = Diagonal Sub-band for 1st Inverse DWT
- *LL, LH, HL, HH* = Sub-bands of CI
- *New_HH2* = Diagonal Sub-band for inverse of APDCBT.
- *APDCBT_Block* = 2-D Matrix of size 128*128 for HH2
- *APDCBT_Message* = 2-D Matrix of size 128*128 for WI
- *New_S* = Updated Singular Values
- *W_Modified* = 2-D Matrix of size 128*128 for modified DWT coefficient
- *U1, S1, V1* = Orthonormal matrices (U1 and V1) and Diagonal Matrix (S1) for APD-CBT_Block
- *U2, S2, V2* = Orthonormal matrices (*U2* and *V2*) and Diagonal Matrix (*S2*) for *APD-CBT_Message*
- *U3, S3, V3* = Orthonormal matrices (*U3* and *V3*) and Diagonal Matrix (*S3*) for *New_S*

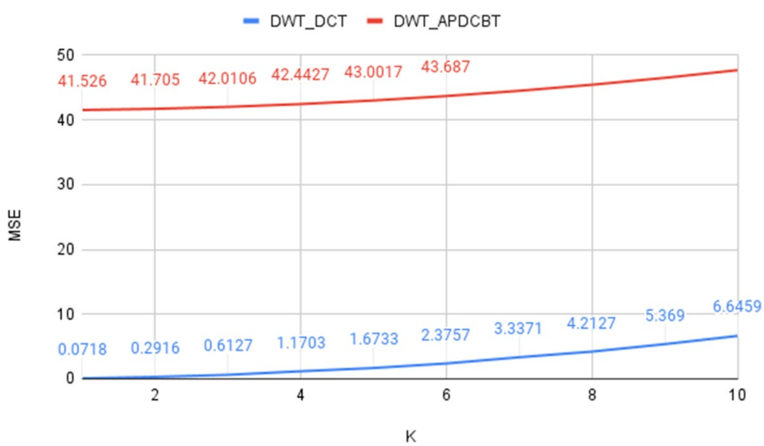


Fig. 6 MSE of Level−1 DWT+DCT and Level-1 DWT+APDCBT

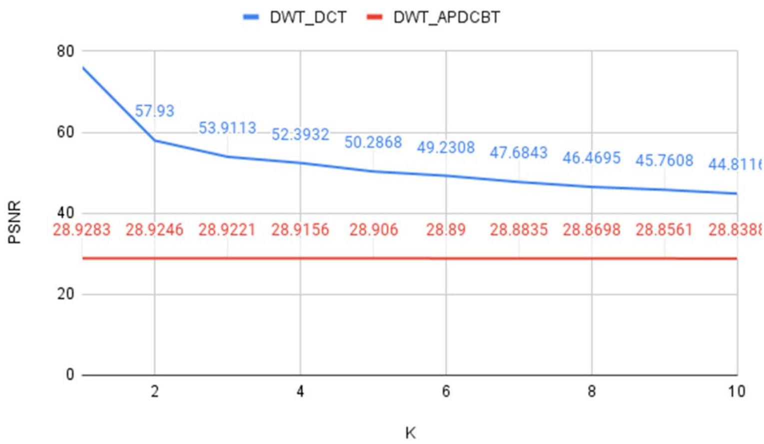


Fig. 7 PSNR of Level−2 DWT+DCT and Level-2 DWT+APDCBT

Step 1. Apply DWT on CI.

- *[LL, LH, HL, HH]* = DWT (*CI*), where we use 'Haar' [27] wavelet compression for efficiency.
- *[LL2, LH2, HL2, HH2]* = DWT (*HH*)

Step 2. Apply APDCBT on each 8*8 block of HH2 to get 'APDCBT_Block'.
Step 3. Find the Singular Values of APDCBT_Block.

- *[U1, S1, V1]* = SVD *(APDCBT_Block)*

Step 4. Compute APDCBT on WI followed by SVD.

- APDCBT_Message = APDCBT (WI)
- [U2, S2, V2] = SVD (APDCBT_Message)

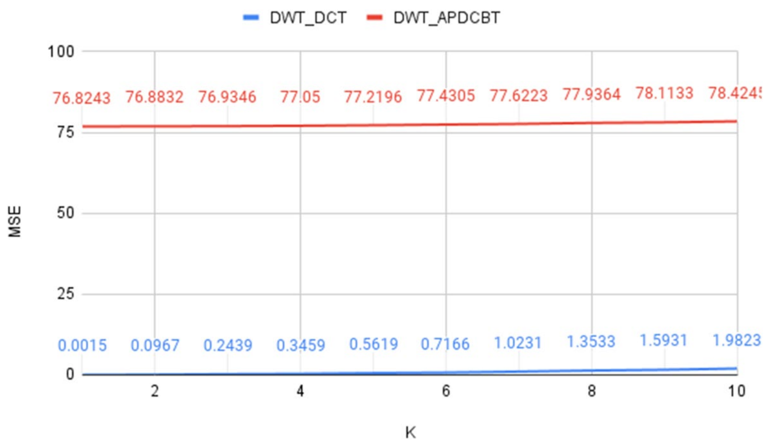


Fig. 8 MSE of Level-2 DWT+DCT and Level-2 DWT+APDCBT

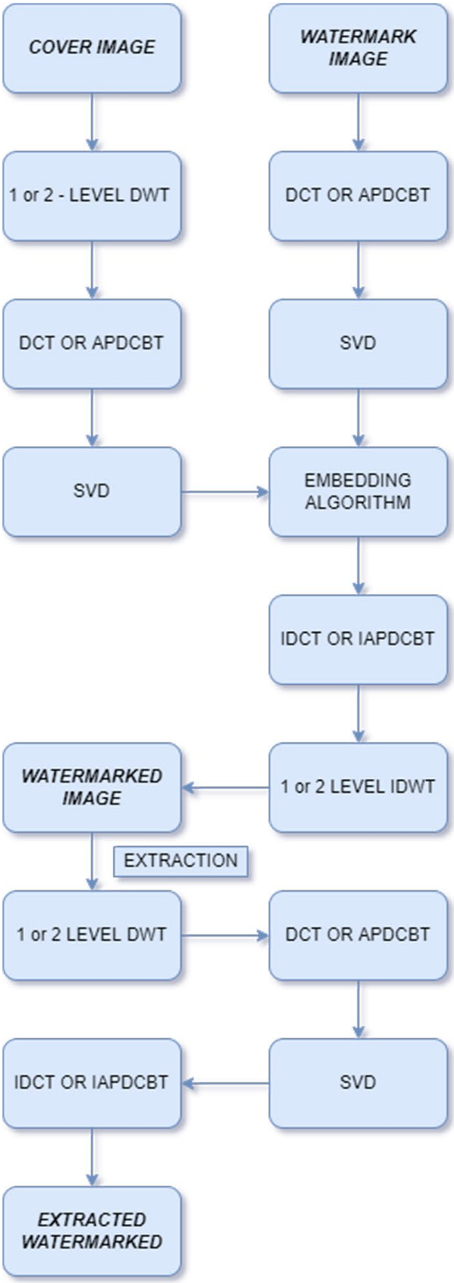


Fig. 9 (1 or 2-Level DWT)+(DCT or APDCBT)+SVD

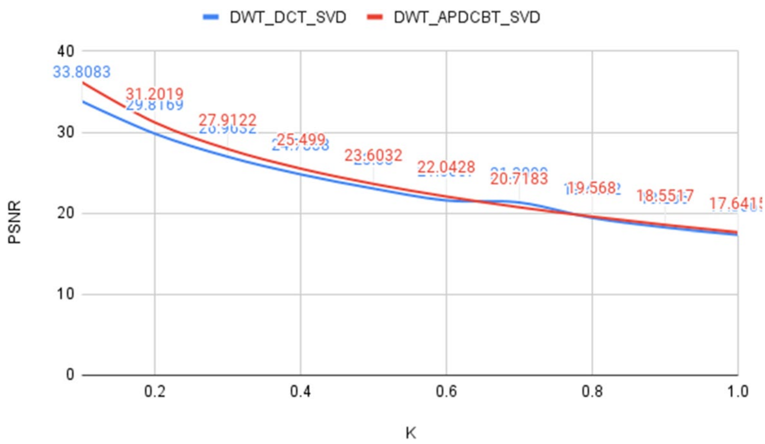


Fig. 10 PSNR of Level-1 DWT+DCT+SVD and Level-1 DWT+APDCBT+SVD

Step 5. Embedding the watermark.

- New_S = S1 + S2*A
- [U3, S3, V3] = SVD (New_S)
- W_Modified = U1*S3*V1

Step 6. Apply Inverse APDCBT and DWT.

- *New_HH2* = Inverse APDCBT (*W_Modified*)
- *New_HH* = Inverse DWT (*LL2, LH2, HL2, New_HH2*) with 'Haar' wavelet compression
- *Final* = Inverse DWT (*LL, LH, HL, New_HH*) with 'Haar' wavelet compression // 'Final' is the embedded watermarked image.

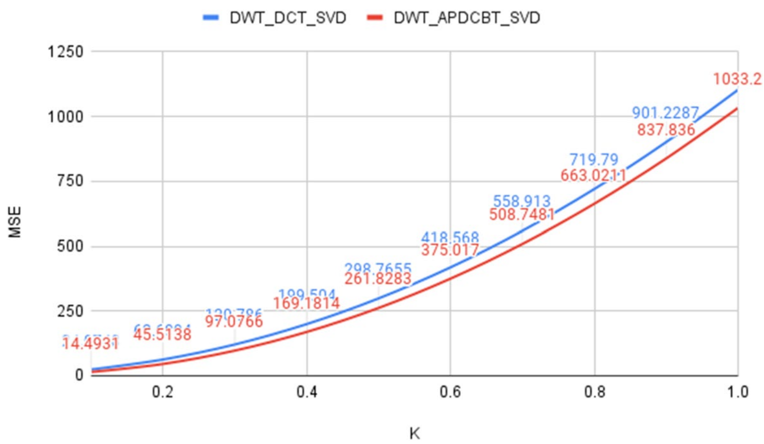


Fig. 11 MSE of Level-1 DWT+DCT+SVD and Level-1 DWT+APDCBT+SVD

Extraction Algorithm:
Variables used:

- *LL, LH, HL, HH* = Sub-bands of Final
- *LL2, LH2, HL2, HH2* = Sub-bands of HH
- *APDCBT_Block* = 2-D matrix of size 128*128 for HH2
- *U3, S3, V3* = Orthonormal matrices (*U3* and *V3*) and Diagonal Matrix (*S3*) for *APDCBT_Block*
- *New_S* = Updated Singular Values
- *U4, S4, V4* = Orthonormal matrices (*U4* and *V4*) and Diagonal Matrix (*S4*) for *APDCBT_Block*

Step 1. Apply DWT on Watermarked Image.

- [LL, LH, HL, HH] = DWT (Final)
- [LL2, LH2, HL2, HH2] = DWT (HH)

Step 2. Apply APDCBT on HH2.

- APDCBT_Block = APDCBT (HH2)

Step 3. Obtain singular values of APDCBT_Block.

- [U3, S3, V3] = SVD (APDCBT_Block)

Step 4. Execute the operation and apply SVD.

- New_S = (S3 – S) / K
- [U4, S4, V4] = SVD (New_S)

Step 5. Perform Inverse APDCBT on modified DWT co-efficient to get retrieved watermark image.

The code for the proposed algorithm is written in MATLAB programming language, as we can easily use the frequency domain watermarking techniques in it.

In order to compare the proposed method with the existing methodologies, we have shown the result we got for PSNR and MSE in Figs. 12 and 13. It clearly states for different values of Scale Factor, the 2-level DWT+APDCBT+SVD depicts more value of PSNR and less value of MSE over 2-level DWT+DCT+SVD. Hence, it is more imperceptible.

6 Discussion

The research paper [17] focuses on modifying the Peak Signal-to-Noise Ratio (PSNR) metric by replacing Mean Squared Error (MSE) with Mean Absolute Percentage Error (MAPE) in the existing system. PSNR-MAPE provides more accuracy in simulating watermarked images. We have used combination of different algorithms, analyse it and also consider the errors, to get best results and our findings suggest that 2-level DWT+SVD+APDCBT

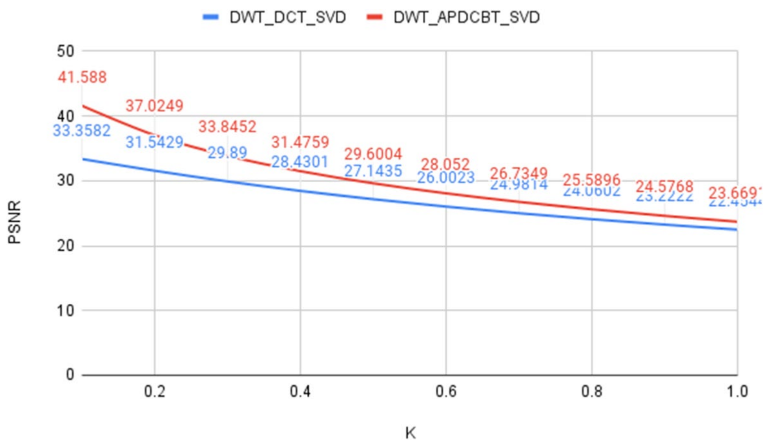


Fig. 12 PSNR of Level-2 DWT+DCT+SVD and Level-2 DWT+APDCBT+SVD (Proposed Algorithm)

outperforms 2-level DWT+SVD+DCT in terms of robustness, imperceptibility, and security. A similar comparison holds for 1-level DWT+SVD+APDCBT and 1-level DWT+SVD+DCT. However, the use of 2-D DCT becomes computationally expensive for larger image sizes due to its time complexity of O(N^2log2N).

The research paper [15] proposes a robust zero-watermarking algorithm based on image moment normalization and 2D-LPEWT-Schur decomposition. It achieves translation, rotation, and scaling invariance through normalization and extracts low-frequency sub-bands using 2D-LPEWT. The algorithm generates a feature matrix through block Schur decomposition and produces a zero-watermark by XORing an encrypted copyright image. It demonstrates robustness against both geometric and non-geometric attacks and outperforms previous methods (CENG et al. and LIU et al.) in terms of resistance to rotation attacks, noise attacks, filtering attacks, JPEG compression attacks, and scaling attacks. Additionally, the algorithm shows potential for zero-watermarking construction of medical images. Similarly, our paper highlights that 2-level

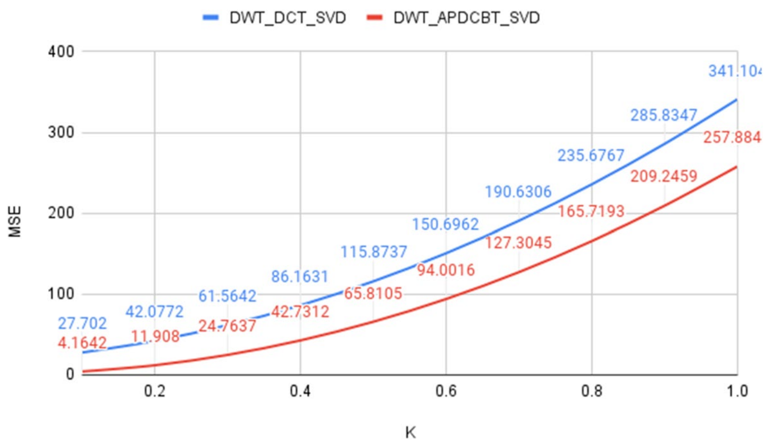


Fig. 13 MSE of Level-2 DWT+DCT+SVD and Level-2 DWT+APDCBT+SVD (Proposed Algorithm)

DWT+SVD+APDCBT surpasses 2-level DWT+SVD+DCT in terms of robustness, imperceptibility, and security. A similar trend is observed in the comparison between 1-level DWT+SVD+APDCBT and 1-level DWT+SVD+DCT. However, the effectiveness of these techniques depends on the image size due to the time complexity of 2-D DCT. Grayscale image watermarking is the focus of the proposed work, but it can be extended to color images by applying the technique to individual color layers (R, G, and B). The same approach can also be applied to video and audio files. It is noted that applying noise to the watermarked image may hinder accurate watermark retrieval. Increasing the scale factor during attacks may result in less precise outcomes. In certain cases, DCT performs better than APDCBT, particularly when embedding the watermark image using the hybrid algorithm DWT+DCT. Moreover, when using the hybrid frequency domain for watermark insertion, 2-level DWT outperforms 1-level DWT.

7 Conclusion

This research paper testifies that 2-level DWT+SVD+APDCBT out-performs 2-level DWT+SVD+DCT in terms of Robustness, Imperceptibility and Security. A similar case is followed in 1-level DWT+SVD+APDCBT and 1-level DWT+SVD+DCT. This can only be done if the image size does not exceed the time complexity because 2-D DCT utilizes O(N2log2N) time to compute when an image is of N*N size. The proposed work is for grayscale image watermarking only, but the same can also be implemented on color images. That is, by selecting a particular layer and applying the watermarking technique in the R, G, and B layers. Not only colored images but similar work can also be done on video and audio files. However, if we apply noise to the watermarked image, it might be difficult to retrieve the watermark image. As we increase the value of the scale factor while performing attacks (like Gaussian noise and salt & pepper noise), we may get less accurate results. Also, it is true that in some cases, DCT overperforms APDCBT. For instance, when we embed the watermark image by applying the hybrid algorithm DWT+DCT. Into the bargain, 2-level DWT outshines 1-level DWT when the hybrid frequency domain is used to insert the watermark image.

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Data availability All relevant data and material are presented in the main paper.

Declarations

Consent for publication Not applicable.

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Competing interests The authors declare that they have no competing interests.

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