

Hybrid Digital Watermarking Using DWT, DCT, And SVD For Robust Image Protection

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Abstract– Proposed model explores Digital Image Watermarking by integrating advanced methodologies such as Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), and Singular Value Decomposition (SVD) to enhance efficiency and accuracy in watermark embedding and extraction. It synthesizes insights from multiple studies, covering fundamental concepts, computational models, and experimental validations. A comparative analysis highlights the effectiveness of these techniques in optimizing robustness and imperceptibility. Performance evaluation based on Peak Signal-to-Noise Ratio (PSNR) and Normalized Correlation (NC) demonstrates significant improvements in watermark quality and resilience against attacks. This research paper contributes to a comparative study of Alpha and NC values for selected 6 attacks and even without attack, as experimental results represented in the form of table and graph.

Index Terms– Digital Watermarking, Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT) and Singular Value Decomposition (SVD).

I. INTRODUCTION

With the development of web communication and multimedia technology, more and more digital multimedia signal can be transmitted through Internet which in turn vulnerable to various attacks. Among today's information security techniques, multimedia watermarking techniques have been developed greatly and become a kind of powerful tool for protecting multimedia content. Watermarking is the process of embedding data into a multimedia content such as an image, audio or video file for the purpose of copy right protection, ownership verification, broadcast monitoring, authentication etc. The important properties of watermarking algorithm include imperceptibility, robustness, security and watermark recovery with or without the original data [1]. In order to be robustness, it is preferred to embed the watermark in perceptually most significant components, but this may affect the visual quality of the image and watermark may become visible. If perceptually insignificant coefficients are selected for embedding then the watermark may be lost by common signal processing operations. Thus determining the place of watermark is a conflict between robustness and fidelity and it is purely application dependent. Generally information could be hidden either by directly modifying the intensity value of pixels or frequency coefficients of an image. The former technique is called spatial domain technique and later is called frequency domain technique. To obtain frequency components of an image, it needs to be transformed using any one of the transformation techniques such as Discrete Fourier Transformation (DFT), Discrete Cosine Transformation (DCT) [3]. Discrete wavelet Transformation (DWT)[4]. In transform domain casting of watermark can be done in full frequency band of an image or in specific frequency band such as in low frequency band or in high frequency band or in middle frequency band. In this paper we proposed a new robust watermarking algorithm that combines the features of discrete wavelet transform, singular value decomposition and discrete cosine transformation techniques. The advantages of the

proposed method are its robustness and its capacity. Robustness is achieved through embedding of watermark in most significant coefficients (DC coefficients) and capacity is increased by using three channels (RGB) of color image. The proposed algorithm is tested against various signal processing operations and many attacks and found that the algorithm is robust. The robustness is tested by measuring the similarity of original and extracted watermark which is more than 90 percent for all kinds of attacks except the rotation attack. The rest of the paper is organized as follows; Review of related works is given in section II. Preliminaries of DWT-DCT-SVD techniques are discussed in section III. Proposed algorithm is discussed in section IV. Performance evaluation is elaborated in section V. Concluding remarks are given in section VI.

II. REVIEW OF RELATED WORKS

Digital image watermarking has been extensively studied to enhance security, robustness, and imperceptibility. Several transformation-based techniques, such as **Discrete Cosine Transform (DCT)**, **Discrete Wavelet Transform (DWT)**, and **Singular Value Decomposition (SVD)**, have been explored to improve the embedding and extraction of watermarks. [1] and [2] provide a fundamental understanding of watermarking and introduce DCT and DWT techniques to embed watermarks while maintaining image quality. However, these techniques have limitations in robustness against attacks, which led to further research. [4] and [5] focus on hybrid models, particularly **DWT-SVD-based watermarking**, to enhance robustness against various attacks, such as noise, compression, and filtering. These studies evaluate watermark imperceptibility and resilience using **Peak Signal-to-Noise Ratio (PSNR)** and **Normalized Correlation (NC)** values, showing significant improvements over traditional methods. Additionally, [6] refines these approaches by integrating artificial intelligence-based optimization techniques, allowing dynamic adjustment of watermarking parameters for better robustness and invisibility. Further research has been conducted on **watermark extraction mechanisms**, especially concerning **the constant α parameter** in the extraction algorithm. The latest paper (2021) provided limited information about these mechanisms, so previous cited works were analyzed to understand them better. A MATLAB-based implementation was carried out for obtaining **objective embedding and extraction algorithms**, and a custom set of **six attacks** was tested to examine the NC values under different attack conditions. The research also identified a behavioral pattern of the extraction algorithm concerning **NC values with varying α parameters**. For better visualization, graphical representations of **α and NC values** were generated, focusing on watermark embedding in the **R-plane and HH frequency band**. The final results demonstrated **graphs of α and NC values for six attacks and even in the absence of attacks**, providing deeper insights into watermark robustness. These findings emphasize the need for adaptive watermarking frameworks that adjust dynamically to varying attack scenarios, ensuring higher security reliability in digital watermarking systems.

III. PRELIMINARIES

A. Discrete Cosine Transform

DCT is another important transformation technique which is widely used due to its energy compaction and decorrelation properties. DCT technique is faster than discrete Fourier transform since the bases are cosine function for the former technique and complex function for the later technique. The transformed matrix consists of both AC and DC coefficients. If the DCT technique is applied on block of size $N \times N$ then it is called block DCT. In DCT transformed block the left top corner element is called as DC coefficient which is perceptually significant and the remaining coefficients are called AC coefficients which are perceptually insignificant. These coefficients are zigzag scanned to obtain frequency components of an image in decreasing order. These DC and AC components are modified to embed watermark in it [3][11]. Equ. 1 and 2 are used for taking transformation and inverse transformation of

an image.

$$c(0,0) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} f(x,y)$$

$$c(u,v) = \frac{2}{\sqrt{MN}} \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} c(u,v) \cos\left(\frac{(2x+1)un}{2M}\right) \cos\left(\frac{(2y+1)vn}{2N}\right) \quad (1)$$

Where $u = 1, \dots, M-1$, $v = 1, \dots, N-1$.

The inverse transform is

$$f(x,y) = \frac{1}{\sqrt{MN}} c(0,0) + \frac{2}{\sqrt{MN}} \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} c(u,v) \cos\left(\frac{(2x+1)un}{2M}\right) \cos\left(\frac{(2y+1)vn}{2N}\right) \quad (2)$$

B. Discrete Wavelet Transform

DWT is a transformation technique is used to represent an image in a new time and frequency scale by decomposing the input image into low frequency, middle and high frequency bands. The value of low frequency band is the averaging value of the filter whereas the high frequency coefficients are wavelet coefficients or detail values. [4].

The DWT can be used to decompose image as a multistage transform. In the first stage, an image is decomposed into four subbands LL1, HL1, LH1, and HH1, where HL1, LH1, and HH1 represent the finest scale wavelet coefficients, while LL1 stands for the coarse level coefficients, i.e., the approximation image. Fig.1 shows the one level wavelet decomposition of an image [1].

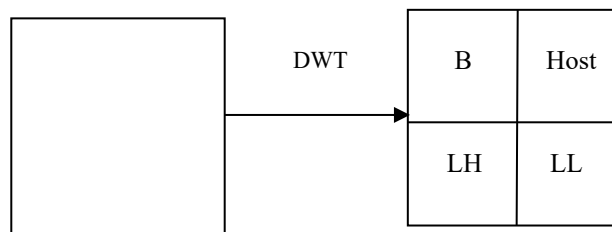


Fig. 1 One level of Wavelet decomposition

C. Singular Value Decomposition

SVD is a mathematical tool used to analyze matrices. In SVD, a given matrix A is decomposed into three matrices such that, $A=USVT$ where U and V are orthogonal matrices and $UTU=I$, $VTV=I$, I is an identity matrix. The diagonal entries of S are called the singular values of A , the columns of U are called the left singular vectors of A , and the columns of V are called the right singular vectors of A . This decomposition is known as the singular value decomposition (SVD) of matrix A . Usually, watermark is embedded in the singular matrix, and if the watermark is embedded in the orthogonal matrices of SVD then the perceptibility of host image is improved it is not robust to many attacks because the matrix elements of orthogonal matrices are very small. The three main properties of SVD from the view point of image processing applications are [4]:

1. The singular values of an image have very good stability, that is, when a small perturbation is added to an image, its singular values do not change significantly.
2. Each Singular value specifies the luminance of an image layer while the corresponding pair of singular vectors specifies the geometry of the image.
3. Singular values represent intrinsic algebraic properties.

IV ALGORITHM FOR EMBEDDING AND EXTRACTING WATERMARK

Proposed algorithm combines the properties of DWT, DCT and SVD techniques to increase the robustness and capacity of the algorithm by selecting significant coefficients and number

of color channels. The procedure for embedding and extracting the watermark is given below.

A. WATERMARK EMBEDDING ALGORITHM

In the proposed work the 'Nanchuck' color image of size 512 x 512 is considered as cover image. DWT technique is applied to decompose the color spaces into different frequency bands using dB1 filter. Watermark size determines the selection of one or all the frequency bands. Each band is divided into many blocks of size 4x4 and DCT is applied to all the blocks. In DCT transformed block the energy is compact in its DC component only. DC matrix is formed by collecting DC components of all the blocks and it is decomposed by SVD technique to get the singular matrix in which watermark is to be hidden. Watermark embedding and extraction process is shown in the Fig. 2 and Fig 3. The steps for embedding watermark are given below.

Let A be the cover image, then

1. Decompose the input image A into RGB color channels
2. Apply DWT to decompose RGB color channels of an image into various frequency bands. Size of the watermark determines the number of color spaces and number of frequency bands for embedding watermark.

$$[LL_R, LH_R, HL_R, HH_R] = 2dw('R', dB1')$$

$$[LL_G, LH_G, HL_G, HH_G] = 2dw('G', dB1')$$

$$[LL_B, LH_B, HL_B, HH_B] = 2dw('B', dB1')$$

Divide the middle frequency band into smaller blocks of size 4x4 and apply DCT to each block,

B_{ij}

$$B_{ij} = DCTLH(B_{ij})$$

3. Extract the DC coefficients σ_{ij} from every DCT transformed blocks, and build a new matrix C, which is decomposed by applying SVD,

$$C = USV^T$$

4. Let W be the watermark and decompose it using SVD technique

$$U_w S_w V_w = (W)$$

5. Modify the singular values of 'C' matrix by using the singular values of watermark.

$$S = S + \gamma S$$

6. Combine the modified singular values with the orthogonal matrices of 'C',

$$S2 = U * S1 * VT$$

7. Replace the original DC's σ_{ij} by the modified DC's $\tilde{\sigma}_{ij}$ in each block $\tilde{B}_{ij}$. Then apply inverse DCT to each

$$B_{ij} = DCTLH(B_{ij})$$

block of low frequency band to reconstruct low frequency band of DWT decomposed image.

8. Step 3 to step 8 is repeated for hiding watermark in other bands of a channel.

9. Step 2 to step 9 is repeated for hiding information in other color channels.

10. Inverse wavelet transformation technique is applied to get the watermarked color space.

11. The RGB color spaces are combined to reconstruct the watermarked image A^w .

B. Watermark Extraction Algorithm

1. Convert the watermarked image into RGB color spaces.

2. Apply DWT to decompose the respective color space of a cover image in which watermark is hidden.

$$[LL, LH, HL, HH]$$

$$= 2dw('colorspace', filename')$$

3. Divide middle frequency band into smaller 4x4 blocks and apply DCT to each block, B^* .

4. Extract the DC coefficients σ_{ij} from every DCT transformed blocks and construct a new matrix C , which could be decomposed by SVD technique,

$$C = U^* S^* V^{*T}$$

5. Extract the singular values from C matrix, then compare the difference between the watermarked singular values and host image singular values, $S_3 = (S^* - S)/\alpha$.

6. Combine the obtained singular values with the orthogonal matrices of watermark, $W^* = U_w S_3 V_w^T$

7. Repeat the same procedure to extract the watermark from other bands.

In the proposed method, to extract the watermark from all frequency bands, it uses original cover image. So, this algorithm can be classified as non-blind watermarking technique. The above embedding and extraction algorithm can be tested for all the three color spaces of (RGB) an image. The embedding of proposed algorithm is shown in Fig. 2. Similarly the extraction process is shown in Fig. 3

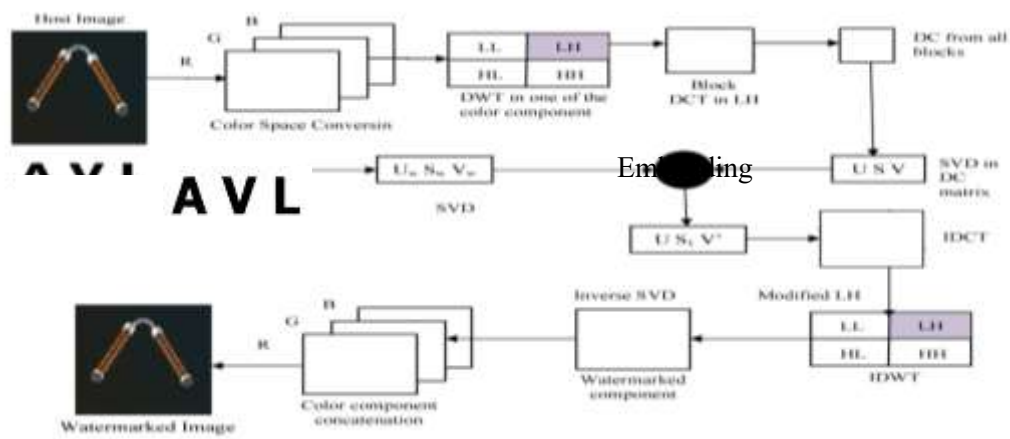


Fig. 2 Watermark embedding process

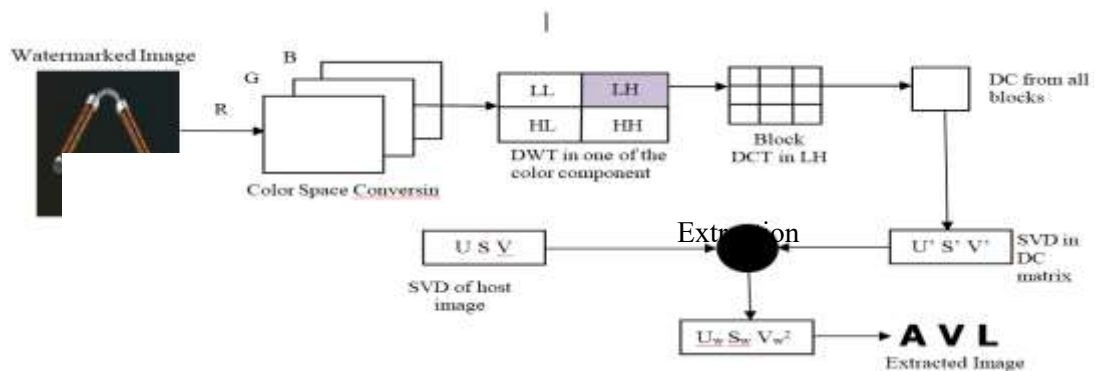


Fig. 3 Watermark extraction process

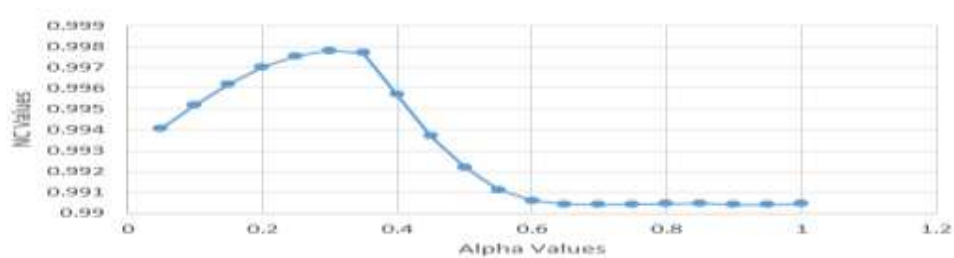
In equation 5 of watermark extraction algorithm there is a formula $S_3 = (S^* - S)/\alpha$.

In this α . For better visualization, graphical representations of α and NC values were generated, focusing on watermark embedding in the **R-plane** and **HH frequency band**. The results demonstrated **graphs of α and NC values for six attacks and even in the absence of attacks**, providing deeper insights into watermark robustness. These findings emphasize the need for adaptive watermarking frameworks that adjust dynamically to varying attack scenarios, ensuring higher security reliability in digital watermarking systems.

Following are the tables and graphs of Alpha values versus NC values for 6 attacks as well as without attacks:

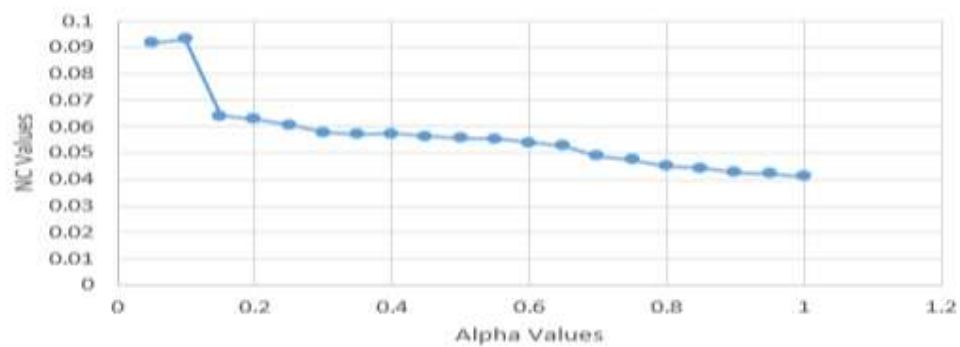
For Sharpening Attack

Alpha Values	NC
0.05	0.994068747
0.1	0.99520229
0.15	0.996191356
0.2	0.99702958
0.25	0.997539352
0.3	0.997810827
0.35	0.997692335
0.4	0.995696182
0.45	0.993697806
0.5	0.992222709
0.55	0.991135084
0.6	0.990609074
0.65	0.99431916
0.7	0.990421681
0.75	0.990433217
0.8	0.990461418
0.85	0.990469502
0.9	0.990409036
0.95	0.990414744
1	0.990468514

**For Gaussian Blur Attack**

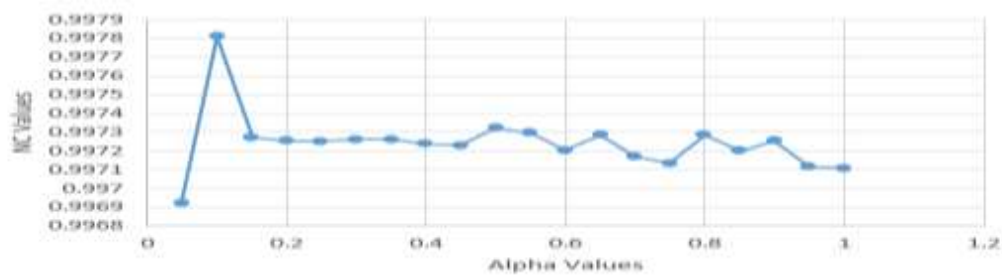
Alpha Values	NC
0.05	0.091782942
0.1	0.093088097
0.15	0.063968848
0.2	0.062865852
0.25	0.060769147
0.3	0.05778019
0.35	0.057125497
0.4	0.057312561
0.45	0.056436516
0.5	0.055729361
0.55	0.05541911
0.6	0.053967321
0.65	0.052747354
0.7	0.048835575
0.75	0.047343395
0.8	0.04493364

0.85	0.044275845
0.9	0.042747871
0.95	0.042219864
1	0.041168772



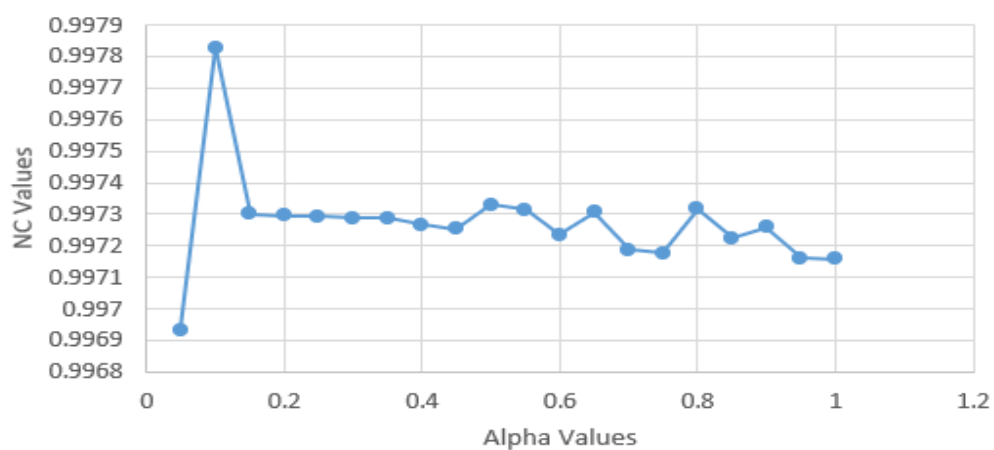
For Horizontal Line Attack

Alpha Values	NC
0.05	0.99692194
0.1	0.99781006
0.15	0.99727174
0.2	0.99725439
0.25	0.99725154
0.3	0.99726001
0.35	0.99726197
0.4	0.99723648
0.45	0.99722798
0.5	0.9973207
0.55	0.9972952
0.6	0.99720361
0.65	0.99728578
0.7	0.99716771
0.75	0.99713281
0.8	0.99728614
0.85	0.99719944
0.9	0.99725191
0.95	0.99711445
1	0.99710778



For Vertical Line Attack

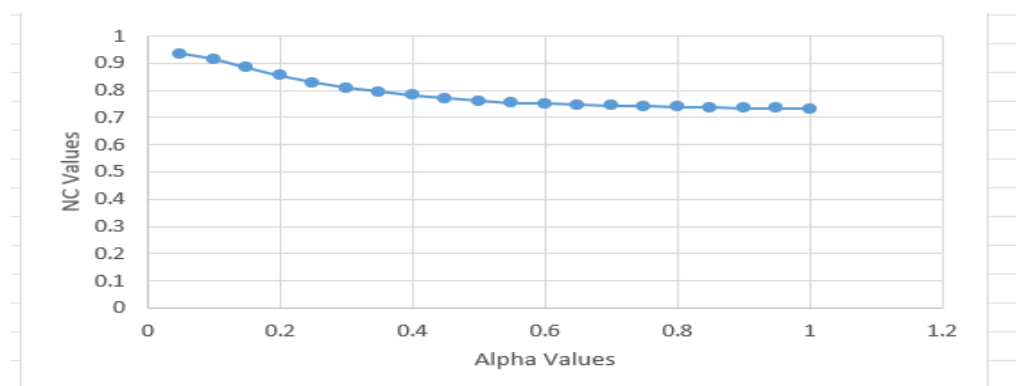
Alpha Values	NC
0.05	0.99693208
0.1	0.99782724
0.15	0.99729955
0.2	0.99729672
0.25	0.99729328
0.3	0.99728868
0.35	0.99728839
0.4	0.99726514
0.45	0.99725284
0.5	0.997333022
0.55	0.99731327
0.6	0.99723542
0.65	0.99730704
0.7	0.99718791
0.75	0.99717623
0.8	0.99731705
0.85	0.99722337
0.9	0.99725733
0.95	0.99716097
1	0.9971568



For salt and pepper Attack

Alpha Values	NC
0.05	0.93409129
0.1	91421746

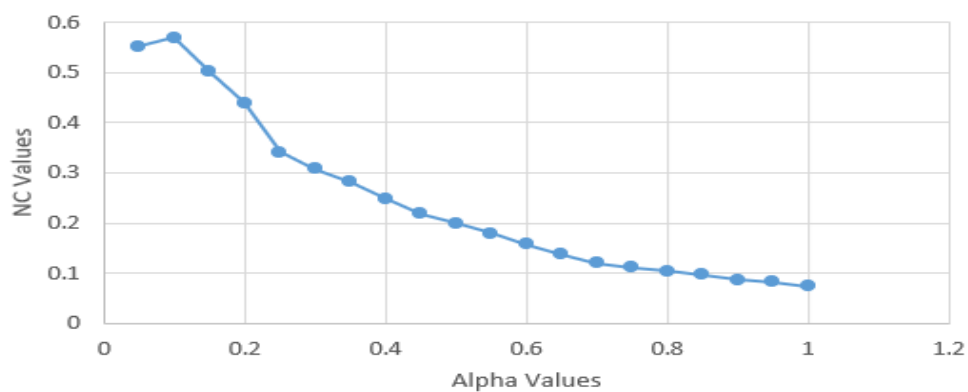
0.15	0.88263958
0.2	0.85389028
0.25	0.82949337
0.3	0.80989047
0.35	0.7943258
0.4	0.78155191
0.45	0.77068237
0.5	0.76100613
0.55	0.75467022
0.6	0.75024311
0.65	0.74703984
0.7	0.74442854
0.75	0.74183118
0.8	0.7387238
0.85	0.73582419
0.9	0.7348894
0.95	0.73356419
1	0.73275131



For Rotational Attack

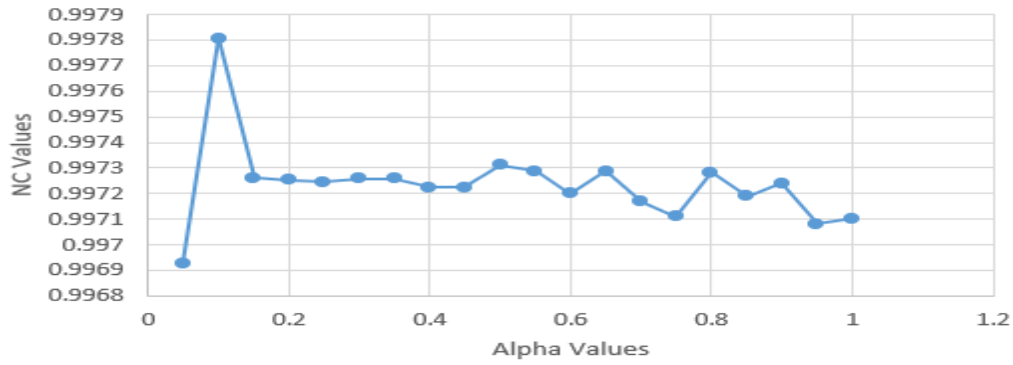
Alpha Values	NC
0.05	0.552193425
0.1	0.568608241
0.15	0.501398097
0.2	0.439079819
0.25	0.340441311
0.3	0.308034226
0.35	0.281996983
0.4	0.248904908
0.45	0.217966174
0.5	0.199294839
0.55	0.179267887
0.6	0.157308103
0.65	0.137368893
0.7	0.120200064

0.75	0.111250826
0.8	0.104814304
0.85	0.097514398
0.9	0.08753031
0.95	0.082621836
1	0.073681702



For No Attack

Alpha Values	NC
0.05	0.996926042
0.1	0.997806734
0.15	0.9972614
0.2	0.997252365
0.25	0.997246344
0.3	0.997258537
0.35	0.997258767
0.4	0.997225013
0.45	0.997223141
0.5	0.997312
0.55	0.997288638
0.6	0.997200379
0.65	0.997288828
0.7	0.997169038
0.75	0.997110656
0.8	0.997281468
0.85	0.99719023
0.9	0.997240514
0.95	0.997081807
1	0.997102305



V. PERFORMANCE EVALUATION

In this proposed algorithm the Nunchaku image of size 512x512 is taken as test image and the size of watermark considered is 64x64. Selected embedding intensity value is varied from 0.05 to 1.00 for all frequency bands. Based on particular application the frequency band and the color channel can be selected. If the size of the watermark is small then any one of the color channel can be selected and application decides the frequency band. This proposed algorithm is tested by embedding watermark in all frequency band of red , green and blue color space.

The original image, watermark and watermarked image are shown in Fig 4(a), 4(b) and 4(c) respectively. Similarly the extracted watermarks are shown in Fig.5.



Fig.4

AVL AVL AVL AVL

The quality of watermarked image is measured using peak signal to noise ratio (PSNR) value and it is observed that the value is 31.0847 db for all color component of RGB color space. Normalized correlation (NC) is a metric through which the degree of similarity between original watermark and extracted watermark is measured. The equation for measuring NC is shown in (5)

$$NC = \frac{\sum_{i=1}^M \sum_{j=1}^N W(i,j) \cdot w'(i,j)}{\sum_{i=1}^M \sum_{j=1}^N W(i,j)^2} \quad (5)$$

If the watermarked image is not altered through intentional or unintentional attacks then the calculated normalized correlation (NC) is 1, means that the original and watermarked image is exactly similar. In the proposed work the watermark is hidden in red color space of the cover image using DWT-DCT-SVD technique and robustness is tested with various attacks such as compression, rotation , salt and pepper noise, Gaussian noise, image sharpening, histogram equalization, Gaussian blur, color contrast, cropping and resizing.

These attacks are not aimed at removing the watermark, but trying to either destroy it or disable its detection and attempt to break the correlation between the extracted and the original watermark. This can be accomplished by shuffling the pixels that is the value of corresponding pixels in the attacked and the original image is the same, however, their location has been changed. Correlation value of extracted watermark after various attacks from red color space is shown in Table 1. Similarly correlation value of extracted watermark from green color space and blue color space after various attacks are shown in Table 2 and Table 3 respectively

The tabulated results show that the NC value is high when watermark is extracted from low frequency components and it is low for high frequency bands for attacks such as salt and pepper noise, Gaussian noise, compression, color contrast and cropping. Similarly the results for sharpening and resizing shows that the NC values for extracted watermark from high frequency bands are more than low frequency bands. But for rotation attack NC value is very low for all frequency components.

TABLE 1.CALCULATED NC VALUES OF EXTRACTED

Fig.5 Extracted watermark from all Frequencies

In order to test the quality of the extracted watermark and cover data both subjective and objective measurements are used. The objective criteria are measured through (3), (4) and (5).

$$MSE = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N (f(o.k) - \hat{f}(i,j))^2 \quad (3)$$

$$PSNR = 10 \log_{10} \left(\frac{255^2}{MSE} \right) \quad (4)$$

As per the table 1, when the watermark is hidden in low and middle frequency band of red color channel the system is withstanding many attacks but it is not true if high frequency band is selected for embedding. System is not robust to cropping. Salt and pepper noise and Gaussian noise attacks when high frequency band is selected for the place of watermark. This algorithm withstanding compression attacks even if the place of a watermark is HH band as the NC value shows the similarity of extracted watermark is more than 70%. But the proposed algorithm is not robust to rotation and cropping attacks.

ATTACKS	LL	LH	HL	HH
Salt and peppers noise	0.945	0.747	0.770	0.750
Horizontal Line	0.915	0.980	0.996	0.998
Rotation	0.490	0.013	0.455	0.476
Sharpening	0.906	0.977	0.997	0.989
Gaussian blur	0.879	0.015	0.111	0.033

TABLE II. MEASURED NC VALUES OF EXTRACTED WATERMARK WATER MARK FROM THE RED COLOR SPACE

ATTACKS	LL	LH	HL	HH
Salt and peppers noise	0.941	0.749	0.769	0.748
Horizontal Line	0.907	0.977	0.998	0.999
Rotation	0.487	0.011	0.453	0.479
Sharpening	0.906	0.976	0.995	0.987
Gaussian blur	0.879	0.013	0.111	0.032
Vertical Line	0.906	0.990	0.996	0.999

TABLE III. MEASURED NC VALUES OF EXTRACTED WATERMARK FROM THE

BLUE COLOR SPACE

Table 3. shows the similarity measure of extracted watermark from blue color space

ATTACKS	LL	LH	HL	HH
Salt and peppers noise	0.941	0.750	0.769	0.747
Horizontal Line	0.906	0.977	0.997	0.998
Rotation	0.487	0.011	0.453	0.479
Sharpening	0.908	0.977	0.995	0.987
Gaussian blur	0.880	0.015	0.113	0.032
Vertical Line	0.908	0.991	0.996	0.997

FROM THE GREEN COLOR SPACE

Table 2 shows the NC values of extracted watermark and the original watermark from the green color channel. If the watermark is hidden in green color channel the system is not withstanding cropping and rotation attacks. The proposed system is robust to noise, sharpening, histogram equalization, color contrast, resize and compression attacks when the watermark is hidden in low (LL) and middle frequency (LH, HL) band. But when it is hidden in HH band it shows 70 % of similarity for compression attack.

TABLE.IV EXTRACTED WATERMARK FROM RED COLOR SPACE

Watermarked image	Extracted from LL	Extracted from LH	Extracted from HL	Extracted from HH
				
NO Attack	0.9068	0.9918	0.9986	0.9987
				
Sharpening	0.9068	0.9760	0.9956	0.9877

Attack				
				
Horizontal Line Attack	0.9073	0.9775	0.9986	0.9997
				
Vertical Line Attack	0.9067	0.9905	0.9962	0.9997
				
Salt And Peppers Attack	0.9419	0.7695	0.7651	0.7489
				
Gaussian Blur Attack	0.8798	0.0133	0.1117	0.0325

				
Rotational Attack	0.4875	0.0111	0.4530	0.0389

V. CONCLUSION

This study explores various digital image watermarking techniques, focusing on **DCT, DWT, and SVD** transformations to achieve robustness, imperceptibility, and security. The review of related works highlights the evolution of watermarking methods from basic transformation-based approaches to advanced hybrid techniques incorporating **DWT-SVD** for improved resistance against attacks. The performance of these methods was evaluated using **PSNR and NC values**, demonstrating their effectiveness in preserving image quality while maintaining watermark resilience. Additionally, a MATLAB-based implementation was carried out to analyse **watermark embedding and extraction algorithms**, considering different **α parameters** to observe their impact on extraction accuracy. The study also involved testing a **custom set of six attacks**, analysing NC values under varying attack conditions, and generating **α vs. NC value graphs** to assess robustness. The results confirm that hybrid approaches, particularly **DWT-SVD-based** watermarking with optimized **α parameters**, significantly enhance resistance against common attacks such as noise, compression, and filtering. The study concludes that **adaptive watermarking frameworks** with dynamic parameter tuning can further strengthen security, making watermarking techniques more reliable for real-world applications. Future work should focus on AI-driven optimization techniques and real-time adaptability to ensure robust watermark protection in diverse multimedia environments.

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