Journal of Science and Technology on Information security

A Robust Watermarking Method Based on RDWT-DCT-SVD in the YCbCr Color Space

DOI: 10.54654/isj.v3i23.1054

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***Abstract*— In digital copyright protection, water-marking plays a crucial role, particularly in ensuring that the watermark remains imperceptible, robust against attacks, and has a high embedding capacity. The new method proposed in this paper utilizes Redundant Discrete Wavelet Transform (RDWT), Discrete Cosine Transform (DCT), and Singular Value De-composition (SVD) to embed the watermark into a color image. Instead of using traditional methods, this approach calculates the Bhattacharyya distance between the original image and the watermark to automatically determine the embedding factor. The watermark is hidden in the Cb channel of the YCbCr color space, which minimizes the impact on the original image quality and enhances both the imperceptibility and robustness of the watermark. Experimental results show that this method not only preserves the original image quality but also withstands various types of attacks, ensuring the watermark retains its integrity and high recoverability.**

***Tóm tắt*— Trong việc bảo vệ bản quyền số, thuỷ vân đóng vai trò quan trọng, đặc biệt là việc đảm bảo thông tin không thể bị phát hiện, bền vững trước các tấn công và có khả năng nhúng cao. Phương pháp mới được đề xuất trong bài viết này sử dụng biến đổi Wavelet rời rạc dự phòng (RDWT), biến đổi Cosine rời rạc (DCT) và phân tích giá trị đặc trưng (SVD) để nhúng dấu thuỷ vân vào ảnh màu. Thay vì sử dụng các phương pháp truyền thống, phương pháp này tính toán khoảng cách Bhattacharyya giữa ảnh gốc và dấu thuỷ vân để xác định hệ số nhúng một cách tự động. Dấu thuỷ vân được giấu trong kênh Cb của không gian màu YCbCr, giúp giảm thiểu tác động đến chất lượng ảnh gốc và nâng cao độ bí mật cũng như tính bền vững của dấu thuỷ vân. Kết quả thử nghiệm cho thấy phương pháp này không chỉ giữ nguyên chất lượng ảnh gốc mà còn chống lại được nhiều loại tấn công khác nhau, đảm bảo dấu thuỷ vân vẫn duy trì tính toàn vẹn và khả năng khôi phục cao.**

***Keywords*— RDWT; DCT; SVD; Bhattacharyya distance; Watermarking.**

***Từ khóa*— RDWT; DCT; SVD; Khoảng cách Bhattacharyya; Thuỷ vân số.**

I. INTRODUCTION

With the rapid development of technology and the Internet, protecting digital content copyrights, particularly images, has become increasingly important. Digital watermarking is an effective method to ensure intellectual property rights and prevent copyright infringements. There are many watermarking methods applied to both text and images. However, achieving a balance between imperceptibility, robustness against attacks, and high embedding capacity remains a challenge.

In this paper, we propose an information hiding method for color images, combining RDWT [1], DCT [2], and SVD [2]. To enhance security and optimize the embedding process, the embed-ding factor is automatically determined through the calculation of the Bhattacharyya distance [3] between the original image and the watermark. Our method selects the Cb channel in the YCbCr color space to hide the watermark, which minimizes the impact on the original image quality as the human eye is more sensitive to luminance than color, while still ensuring high security. Experimental results demonstrate that this method not only preserves the original image

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This manuscript was received on September 6, 2024. It was reviewed on October 22, 2024, revised on November 13, 2024 and accepted on November 20, 2024.

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quality but also withstands various types of attacks, ensuring the watermark can be accurately recovered.

The main contributions of this paper are as follows:

- Propose a watermark embedding scheme based on RDWT-DCT-SVD.
- Use the Cb channel in the YCbCr color space and the Bhattacharyya distance to compute the embedding factor, ensuring a balance between the imperceptibility and robustness of the watermark.

The remainder of the paper is organized as follows. Section II summarizes previous studies on robust frequency domain watermarking based on RDWT, DCT, and SVD. The proposed method is described in Section III. Section IV presents experimental results along with analysis. Conclusions and future work are discussed in Section V.

II. RELATED WORK

In recent years, along with the development of the internet, digital copyright protection has become increasingly important. As a result, digital watermarking has also evolved to enhance imperceptibility, robustness, and the capacity to hide large amounts of information. Many methods have been developed. In addition to traditional methods, hybrid methods are favored due to the numerous benefits they offer.

Roy et al. [4] proposed a watermarking scheme for BGR images. The image is converted to the YCbCr color space, and the Y channel is selected, using a combination of 3-level discrete wavelet transform (DWT) and SVD. Rajani et al. [5] introduced a method that combines RDWT with DCT.

Singh et al. [6] proposed an efficient watermark embedding method using Haar discrete wavelet transform (DWT), DCT, and SVD, ensuring high robustness. Meanwhile, Zear et al. [7] also combined DWT-DCT-SVD to create a robust watermarking scheme, where a 3-level DWT was applied to enhance the watermark's robustness. Recently, Dong et al. [8] also used a combination of DWT-DCT-SVD in the YCbCr color space, while utilizing Lorenz hyperchaotic mapping to enhance security.

DWT faces the issue of downsampling, and shift invariance is not guaranteed, which leads to inaccurate watermark extraction. Hence, RDWT is used to solve this problem [1]. Many watermark embedding schemes using RDWT have been proposed. Gaur et al. [9] introduced a hybrid RDWT-DCT-SVD method, where the watermark embedding is performed on two sub-bands, LH and HL. Later, in 2018, Khare et al. [1] proposed a scheme based on RDWT, selecting the LL sub-band. In addition, there are many studies based on RDWT, such as those by Roy et al. [10], Bajaj et al. [2], Singh et al. [11], Rajani et al. [5], and Jamal et al. [12]. A recent study by Awasthi et al [13] introduced a combination of using both Y and Cb components in the YCbCr color space, along with RDWT-DCT-SVD, to increase robustness and security. Overall, studies using RDWT still manually select the embedding factor, which affects practical usage, as each image and watermark work best with different embedding factors.

III. THE PROPOSED WATERMARKING SCHEMA

In this section, we present the proposed watermark embedding scheme.

A. Self-adjusting embedding factor

Determining the embedding factor is a critical element, requiring a proper balance between the robustness and imperceptibility of the watermark. If the embedding factor is too low, the watermark may be easily detected or removed by external influences. Conversely, if the embedding factor is too high, the image quality will be significantly affected, reducing the imperceptibility of the watermark.

The Bhattacharyya distance [3] is a method used to evaluate the similarity between two discrete probability distributions p and q over the same domain X, defined as:

$$d_b(p,q) = -ln\left(\sum_{x\in X}\sqrt{p(x)q(x)}\right) \quad (1)$$

Histograms are used to represent the pixel intensity distributions of both the original image and the watermark. These histograms are then normalized to create probability distributions with values ranging from 0 to 1 which are referred to as p and q, respectively. p(x) and q(x) are the probability values at bin x of the two histograms.

Our proposed method uses the Bhattacharyya distance between the original image and the watermark to automatically determine the embedding factor. The Bhattacharyya distance is a measure of similarity between two probability distributions, allowing the embedding factor to be adjusted based on the similarity between the original image and the watermark. This optimizes the embedding process, ensuring that the watermark remains hidden while maintaining high robustness. The formula for calculating the embedding factor is defined as follows [8]:

$$\alpha = \lambda \times \frac{1}{1 + e^{d}} \quad (2)$$

where λ is an adjustment parameter with a value ranging from 0 to 1, and d is the Bhattacharyya distance between the original image and the watermark, which is calculated from Equation (1).

B. Watermark embedding process

In this scheme, the original image is an RGB color image, and the watermark is a grayscale image. The RDWT is applied, followed by the DCT on the LL sub-band, and finally, SVD is performed on the DCT-transformed image for both the original image and the watermark. To enhance the imperceptibility of the algorithm, we convert the original image to the YCbCr color space and then select the Cb channel to perform watermark embedding. The Cb channel is chosen because the human eye is highly sensitive to changes in luminance but less sensitive to changes in color. The embedding factor is calculated using the Bhattacharyya distance between the original image and the watermark, and then the embedding process is carried out. The steps for embedding the watermark are illustrated in Figure 1.

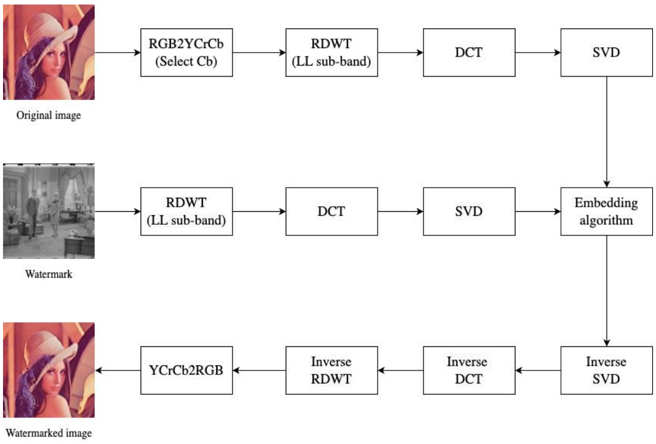


Figure 1. The watermark embedding process

The steps of the watermark embedding process are as follows:

1) Definitions:

- Original image: C
- Watermark: W

2) Read the watermark and apply the first-level redundant discrete wavelet transform (RDWT) to decompose it into four sub-bands: LL_W, LH_W, HL_W and HH_W.

$$[LL_W,\ LH_W,\ HL_W, HH_W\ ] = \ RDWT(W)$$

3) Apply the discrete cosine transform (DCT) on the LLW sub-band.

$$LL_{DW} = DCT(LL_W)$$

4) Perform singular value decomposition (SVD) on the DCT-transformed LL_W sub-band to decompose it into three matrices: U_W, S_W, and V_W.

$$[U_W,\ S_W,\ V_W] = SVD(LL_{DW})$$

5) Convert the original color image to the YCbCr color space and select the Cb channel for watermark embedding.

$$[Y, Cb, Cr] = RGB2YCbCr(C_{RGB})$$

6) Apply the first-level RDWT on the Cb channel to decompose it into four sub-bands: LL_C, LH_C, HL_C and HH_C.

$$[LL_C, HL_C, HL_C, HH_C] = RDWT(Cb)$$

7) Apply the DCT on the LL_C sub-band.

$$LL_{DC} = DCT(LL_C)$$

8) Perform SVD on the DCT-transformed LL_C sub-band to obtain three matrices: U_C, S_C, and V_C.

$$[U_C,\ S_C,\ V_C] = SVD(LL_C)$$

9) Use the embedding factor α, calculated from Equation 2, to embed the watermark by blending the S_W matrix from the watermark with the S_C matrix from the original image.

$$S'_C = \alpha \times S_W + (1-\alpha) \times S_C$$

10) Reconstruct the LL_C sub-band using the matrices U_C, S'_C and V_C.

$$LL'_C = U_C \times S'_C \times V_C^T$$

11) Perform inverse DCT on LL'_{DC} to recover the LL_C sub-band after watermark embedding.

$$LL'_C = IDCT(LL'_{DC})$$

12) Use the sub-bands LL'_C, LH_C, HL_C and HH_C to reconstruct the Cb channel through inverse RDWT.

$$Cb' = IRDWT(LL'_C, LH_C, HL_C, HH_C)$$

13) Finally, combine the Cb' channel with the original Y and Cr channels to recreate the color image with the embedded watermark.

$$C'_{RGB} = YCbCr2RGB(Y, Cb', Cr)$$

C. Watermark embedding process

During the extraction process, the watermarked image is converted to the YCbCr color space, followed by the application of RDWT, DCT and SVD to ensure accurate recovery of the watermark. The steps below describe the detailed watermark extraction process.

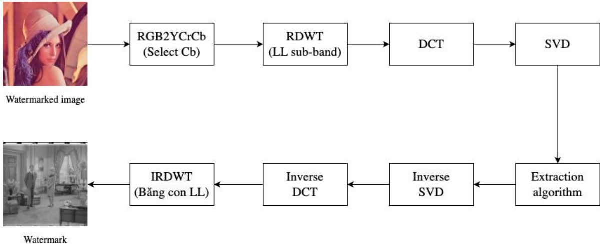


Figure 2. The watermark extraction process

The steps of the watermark embedding process are as follows:

1) Definitions:

- Watermarked image: M

Read the watermarked image and convert it to the YCbCr color space. Then, select the Cb channel of the embedded image for further processing.

$$[M_Y,\ M_{Cb},\ M_{Cr}] = RGB2YCbCr(M_{RGB})$$

3) Apply the first-level RDWT on the Cb channel of the image to decompose it into four sub-bands: LL_W, LH_W, HL_W and HH_W.

$$[LL_M,\ HL_M,\ LH_M,\ HH_M] = RDWT(M_{Cb})$$

4) Apply the DCT on the LL_M sub-band of the watermarked image.

$$LL_{DM} = DCT(LL_M)$$

5) Perform SVD on the LL_{DM} sub-band to obtain the matrices U_M, S_M, and V_M.

$$[U_M,\ S_M,\ V_M] = SVD(LL_{DM})$$

6) Use the embedding factor α calculated from the embedding process, along with the S_C matrix of the original image, to extract the singular value matrix S'_W of the watermark.

$$S'_W = \frac{S_M - (1-\alpha) \times S_C}{\alpha}$$

7) Perform inverse SVD from the S'_W matrix, along with the corresponding U_W and V_W matrices.

$$W'_E = U_W \times S'_W \times V_W^T$$

8) Perform inverse DCT on W'_E to restore the LL sub-band.

$$LL'_W = IDCT(W'_E)$$

9) Perform inverse RDWT from the LL'_W sub-band and corresponding sub-bands to recover the original watermark.

$$W' = IRDWT(LL'_W, HL_W, LH_W, HH_W)$$

IV. RESULTS AND ANALYSIS

In this section, we present the experimental results and evaluation of the proposed method in this paper. In this study, two main metrics, Peak Signal-to-Noise Ratio (PSNR) [1] and Structural Similarity Index (SSIM) [14], were chosen to evaluate the watermark embedding method applied to six different original images. Additionally, the

Normalized Correlation Coefficient (NCC) [9] was used to measure the robustness of the watermark. The original RGB images (512 x 512) and the gray watermark (512 x 512) were obtained from the USC-SIPI dataset [15] and the CVG-UGR dataset [16]. The experiment was conducted in a Python 3.12 environment, on a computer with an Apple M1 processor and 16 GB of RAM. The embedding factor was calculated according to Equation (2) with $\lambda = 0.1$.

TABLE 1. PSNR, SSIM, AND NCC VALUES

	PSNR	**SSIM**	**NCC**
Lena	49.092	0.996	0.999
Baboon	49.787	0.998	0.999
Airplane	47.816	0.995	0.999
Sailboat on lake	48.790	0.997	0.999
Peppers	48.527	0.990	0.999
House	49.205	0.997	0.999

Analysis

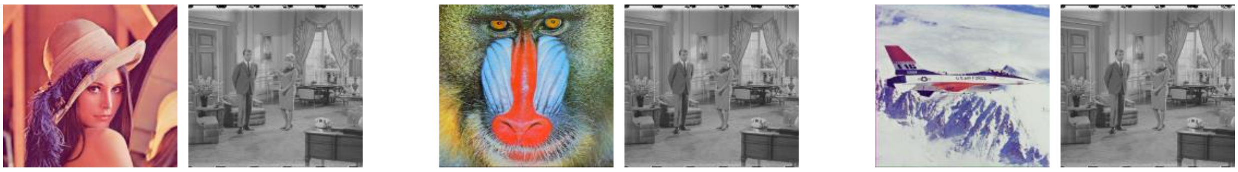
In this study, we used various types of attacks in the experiments, including: Salt and pepper noise (m = 0, v = 0.05), Gaussian noise (m = 0, v=0.05), Speckle noise (m = 0, v = 0.05), Sharpening, Gaussian filter, Mean filtering (3x3), Rotation (10°), JPEG (QF = 90), and cropping (20%). The results are shown in figures 4 and 5, corresponding to the sequence from (a) to (i) for the different types of attacks.

1. Imperceptibility

The imperceptibility of the watermark means that the difference between the watermarked image and the original image is hardly noticeable to the naked eye. Table 1 shows the PSNR and SSIM values of the different original images without any attack. Figure 3 shows the embedded images and their extracted watermarks. The average PSNR and SSIM values of this method are 48.8695 dB and 0.996, respectively. Table 5 shows the comparison results of the average PSNR values of the watermarked image with other methods. It can be concluded that the proposed method's NCC and PSNR values are generally higher than those of other methods. Additionally, the average NCC value achieved is 0.999. This demonstrates that the method has excellent imperceptibility.

2. Imperceptibility

The robustness of a watermark is evaluated by its ability to withstand different types of attacks. The test attacks included noise attacks, advanced technology attacks, geometric transformations, and compression. The results show that the proposed method can withstand most attacks except for rotation and cropping attacks, and the extracted watermark only exhibits minor distortion. The NCC metric is used to demonstrate the high robustness of this method. Table 4 shows the NCC values of the original images after various attacks. The NCC values are all above 0.9, and for some attacks, the NCC value can reach up to 0.999. Table 3 shows the PSNR of the watermark after being attacked. Under various attacks, the average PSNR values is 34.4658, which is an acceptable value. Table 2 shows the PSNR values of the watermarked images after being attacked. From Table 2 and Table 3, it can be observed that for various attacks, the quality of the watermarked image significantly decreases. However, the extracted watermark still maintains fairly good quality. As seen in Table 3, the average PSNR value of the watermark reaches 23.0861 dB. Table 6 shows the comparison results of the average NCC value of the watermark with other methods. It can be concluded that the proposed method's NCC values are generally higher than those of other methods. This indicates that the robustness of the method is good.



a) Lena with watermark — Extracted watermark — b) Baboon with watermark — Extracted watermark — c) Airplane with watermark — Extracted watermark

d) Sailboat with watermark — Extracted watermark — e) Peppers with watermark — Extracted watermark — a) House with watermark — Extracted watermark

Figure 3. Watermarked image and corresponding extracted watermark

Figure 4. Watermarked image with various types of attack

TABLE 2. PSNR VALUES OF WATERMARKED IMAGES WITH DIFFERENT ATTACKS

Type of attack	Lena	Baboon	Airplane	Sailboat	Peppers	House
Salt and pepper noise (m = 0, v = 0.05)	38.634	38.214	37.009	37.504	37.009	37.626
Gaussian noise (m = 0, v = 0.05)	44.498	45.395	45.732	46.224	46.086	46.507
Speckle noise (m = 0, v = 0.05)	28.589	28.547	28.071	28.822	28.835	28.304
Sharpening	29.155	28.074	29.959	28.394	28.586	29.470
Gaussian filter	35.197	30.036	35.721	32.349	34.037	33.691
Mean filtering (3 x 3)	34.678	29.762	35.035	31.862	33.518	33.034
Rotation (10°)	28.617	28.217	29.451	28.687	28.546	28.716
JPEG (QF = 90)	35.588	31.216	35.585	32.164	33.473	34.542
Crop (20%)	40.519	40.700	39.866	40.338	40.316	40.451

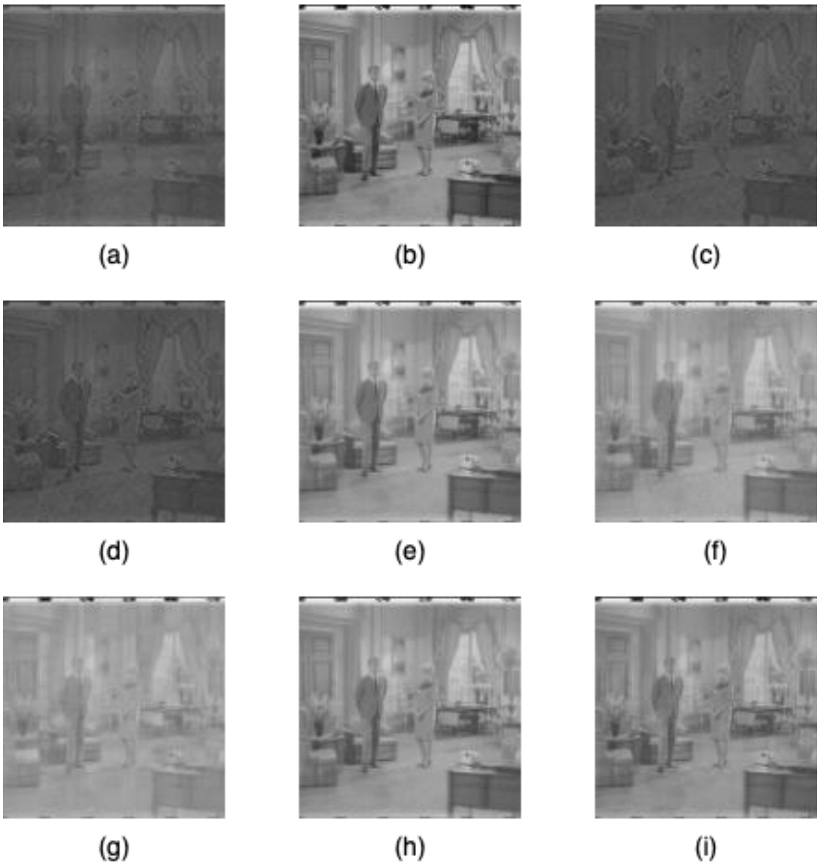


Figure 5. Watermark image extracted from various types of attacks

TABLE 3. PSNR VALUES OF THE WATERMARK WITH DIFFERENT ATTACKS

Type of attack	Lena	Baboon	Airplane	Sailboat	Peppers	House
No Attack	33,820	34,023	31,258	33,787	33,180	33,809
Salt and pepper noise (m = 0, v = 0.05)	22.341	26.526	26.282	29.972	21.368	27.904
Gaussian noise (m = 0, v = 0.05)	27.633	28.171	27.998	28.059	27.319	28.158
Speckle noise (m = 0, v = 0.05)	18.508	19.634	15.415	17.742	20.121	15.309
Sharpening	19.745	14.272	21.876	18.353	20.070	19.365
Gaussian filter	29.667	24.126	24.613	22.216	23.179	23.491
Mean filtering (3 x 3)	23.578	17.335	23.884	21.386	22.460	22.611
Rotation (10°)	21.032	16.807	16.416	23.091	14.015	22.755
JPEG (QF = 90)	22.038	25.797	30.591	28.900	24.900	24.266
Crop (20%)	30.316	21.274	26.212	32.388	21.968	23.201

3. *Embedding capacity*

In our proposed method, we using RDWT-DCT-SVD. RDWT has shift invariant property due to this, RDWT based watermarking method is more embedding capability than DWT based watermarking techniques. Embedding capacity, which refers to the number of bits that can be embedded per pixel in the original image [17], is another aspect to consider. Our method uses a RGB 512x512 original image and a gray 512x512 watermark, achieving an embedding capacity of (512 x 512 x 8) / (512 x 512 x 3) = 2.67 bpp. This result is quite high compared to conventional watermarking methods.

TABLE 4. NCC VALUES OF THE WATERMARK WITH DIFFERENT ATTACKS

Type of attack	***Lena***	***Baboon***	***Airplane***	***Sailboat***	***Peppers***	***House***
Salt and pepper noise (m = 0, v = 0.05)	***0.989***	***0.995***	***0.998***	***0.998***	***0.992***	***0.996***
Gaussian noise (m = 0, v = 0.05)	0.999	0.999	0.999	0.999	0.999	0.999
Speckle noise (m = 0, v = 0.05)	0.975	0.978	0.950	0.968	0.9815	0.948
Sharpening	0.979	0.939	0.987	0.970	0.980	0.978
Gaussian filter	0.998	0.993	0.996	0.991	0.995	0.994
Mean filtering (3 x 3)	0.994	0.964	0.995	0.988	0.993	0.992
Rotation (10°)	0.987	0.968	0.969	0.991	0.989	0.990
JPEG (QF = 90)	0.990	0.995	0.998	0.997	0.995	0.994
Crop (20%)	0.998	0.985	0.999	0.998	0.995	0.991

TABLE 5. COMPARISON OF AVERAGE PSNR VALUES OF SCHEMES UNDER DIFFERENT ATTACKS

Type of attack	**Proposed**	**[8]**
Salt and pepper noise (m = 0, v = 0.05)	37.8327	24.2262
Gaussian noise (m = 0, v = 0.05)	45.5737	21.4326
Speckle noise (m = 0, v = 0.05)	28.5280	24.3508
Sharpening	28.9397	20.5305
Gaussian filter	33.5052	25.8926
Mean filtering (3 x 3)	33.1482	25.6279
Rotation (10°)	29.0390	12.5848
JPEG (QF = 90)	33.7613	27.1387
Crop (20%)	40.1983	19.0234

TABLE 6. COMPARISON OF AVERAGE NCC VALUES OF SCHEMES UNDER DIFFERENT ATTACKS

Type of attack	**Proposed**	**[10]**	**[8]**	**[4]**
Salt and pepper noise (m = 0, v = 0.05)	**0.9946**	-	0.9945	0.9583
Gaussian noise (m = 0, v = 0.05)	**0.9990**	0.8339	0.9158	0.9294
Speckle noise (m = 0, v = 0.05)	**0.9667**	-	0.9924	0.9625
Sharpening	**0.9721**	0.8560	0.9489	0.9385
Gaussian filter	**0.9945**	0.8186	0.9867	-
Mean filtering (3 x 3)	**0.9876**	0.8271	0.9827	0.9796
Rotation (10°)	**0.9823**	-	0.8699	-
JPEG (QF = 90)	0.9948	0.9479	**0.9990**	-
Crop (20%)	**0.9943**	-	0.9466	-

V. CONCLUSION

In this study, the method using RDWT-DCT-SVD in the YCbCr color space, along with the self-adjusting embedding factor, has shown significant improvements in imperceptibility, robustness, and embedding capacity. The watermarked image is almost undetectable, ensuring high imperceptibility. This method also demonstrates strong resilience against attacks, preserving both image quality and embedded information. Notably, the high embedding capacity allows for the storage of a large amount of information while maintaining high image quality, confirming the effectiveness of this method in practical applications.

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