

Comparative Analysis of Digital Image Watermarking Techniques

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Abstract

This research involves in the juxtaposed assessment of 4 digital image watermarking techniques. ADW (Additive Watermarking), LSB (Least Significant Bit), DWT (Discrete Wavelet Transform), DWT-DCT (Discrete Cosine Transform)-QR (QR Decomposition). The comparison is in terms of Imperceptibility and Robustness which are evaluated implementing PSNR (Peak Signal to Noise Ratio) and NCC (Normalized Cross Correlation) respectively. 12 Attacks were simulated. The DWT technique demonstrates the highest robustness, achieving an average NCC of 0.9998 under no attacks and 0.9272 under attacks, along with a consistent PSNR of 58.0933. The DWT-DCT-QR method offers competitive robustness, with an average NCC of 0.98322 under no attacks and 0.9138 under attacks, while achieving an average PSNR of 59.72448. The ADW technique prioritizes robustness, achieving an average NCC of 0.8245 under attacks but with a lower PSNR of 32.74826 dB, indicating reduced imperceptibility. In contrast, the LSB technique achieves excellent imperceptibility with an average PSNR of 63.9774 and a perfect NCC of 0.9993 under no attacks but drops to an average NCC of 0.6568 under attacks. These results highlight the DWT and DWT-DCT-QR techniques as the most suitable for applications requiring a balance between imperceptibility and watermark robustness.

Keywords: ADW, LSB, DWT, DWT-DCT-QR, PSNR, NCC.

1. Introduction

Data that is sent digitally, such as audio, visuals, or images, could include a minor identifier built into it through the technique of digital watermarking. By identifying this indicator, a computer algorithm can ensure that the data being delivered is genuine and trustworthy. Adding a marker to a picture is called digital image watermarking. Digital picture watermarking has several uses, such as in forensics, fighting pirates' endeavours, content filtering, broadcast surveillance, medical applications, ownership and copyright declaration. Watermarking techniques are typically researched and utilized in two distinct processing domains that include the domain of space and the domain of transformation. The execution of spatial domain strategies is notably straightforward, but they lead to dropped imperceptibility due to altering the pixels of the underlying picture. Multiple methods are used, including least significant bit substitution, patchwork, texture mapping coding, predictive coding, and additive watermarking processes. Multiple image transforms such as the DFT, DCT and DWT are used to convert the host image into the frequency domain in transform domain

approaches. Following the process of transform, the watermark is ingrained and then the image endures an inverse transformation. In [1], the Additive watermarking involves the utilization of M pseudorandom noise (PN) sequences to systematically alter the blocks of the host images. The application of PN sequences facilitates the blind detection of watermarks attributable to their superior correlation characteristics. The LSB substitution methodology delineated in [2] involves the critical bits of the watermark incorporated within the least significant bits of the host data. In the context of an 8-bit image, the visual information is predominantly represented in the most significant bit plane, whereas the least significant bit plane exhibits an absence of any discernible visual information. The image's numerous levels of information are preserved by each and every bit plane. For this purpose, the watermarking program choose the bit plane with the least amount of visual impact. ADW [1] and LSB [2], pertain to methodologies classified under blind watermarking techniques.

In the realm of DWT [3] watermarking, the watermark is affixed to the frequency coefficients of the original image through the execution of mathematical

formulations that incorporate operations of addition and multiplication. The alterations made via these mathematical formulations ought to remain sufficiently minimal to evade detection, yet must be pronounced enough to be perceptible. By monitoring the changes in the chosen coefficients, one can retrieve the watermark data. Via the aid of the DCT [3], QR decomposition [4], and the DWT, several watermarking techniques [5,6,7,8] were proposed. One such technique is [9] which utilized all the three DCT, QR, DWT. In [9], Judging on their entropy levels, particular sections of the host image have been selected for use with the watermarking embedding technique. For the purpose of finding the extent to which watermark is unnoticeable in the watermarked image is, PSNR is computed; in order to figure out the strength of the acquired watermark is, NCC is computed.

This work presents the actualization of about 4 watermarking techniques. The current research contrasts these strategies depending upon their Imperceptibility and robustness. To assess the degree of imperceptibility and robustness of a specific watermarking method, PSNR and NCC IQA metrics were calculated, 12 attacks were simulated. PSNR, NCC were calculated to evaluate Imperceptibility and Robustness, respectively.

2. Methodologies for Watermarking Implementation

The watermarking methodologies delineated in this manuscript encompass ADW (Additive watermarking), LSB (Least Significant Bit), DWT, DWT-DCT-QR techniques. The selection of these techniques was made to provide a comparative analysis between spatial and frequency domain methods. LSB and ADW represent spatial domain techniques, which are generally known for their high imperceptibility but lower robustness against attacks. In contrast, DWT and DWT-DCT-QR belong to the frequency domain, which typically offers improved robustness at the cost of slightly reduced imperceptibility.

2.1. ADW Technique

2.1.1 Embedding Watermark

- Read the gray scale $M \times N$ (512 X 512) host image.
- Read the gray scale $M_b \times N_b$ (128 X 128) watermark image.

- Define the block size for dividing the host image into blocks, calculated as $B_r = \frac{M}{M_b}$ and $B_c = \frac{N}{N_b}$, where M , N and M_b , N_b are the dimensions of host and watermark image respectively. Set a gain factor K to control watermark embedding visibility.
- Divide Host Image into Blocks, $B_r \times B_c$.
- Generate two Block based noise sequences S_1 , S_2 scaled to intensity range [0,255] with the help of a secret key. Normalize both sequences to zero mean.
- Initialize an empty watermark mask (w_m) of size ($M \times N$) for each block in the host image ($i=1$ to B_r , $j=1$ to B_c), extract the corresponding pixel value (w_{ij}) from the watermark image. Assign noise sequences to the watermark mask, if $w_{ij} < 128$ assign S_1 to the corresponding block in w_m , otherwise, assign S_2 .
- Embed the watermark by adding the scaled watermark mask ($K \cdot w_m$) to the host image ht

$$wkd = ht + K \cdot w_m \quad (1)$$
- save the watermarked image, wkd .

2.1.2 Extracting watermark

- Define the size of the extracted watermark ewk as $M_b \times N_b$.
- Divide the watermarked image wkd into blocks of size $B_r \times B_c$. Initialize an empty matrix for the extracted watermark.
- For each block in the watermarked image ($i=1$ to B_r , $j=1$ to B_c), Extract the block of size ($B_r \times B_c$) from wkd corresponding to block indices (i, j).
- Compute the correlations of the extracted block with each noise sequence, $correlation_1$ and $correlation_2$.

$$correlation_1 = \frac{\sum \sum (block \cdot S_1)}{\sqrt{\sum \sum (block^2) \cdot \sum \sum (S_1^2)}} \quad (2)$$

$$correlation_2 = \frac{\sum \sum (block \cdot S_2)}{\sqrt{\sum \sum (block^2) \cdot \sum \sum (S_2^2)}} \quad (3)$$

- Compare the correlations to decide the watermark bit. If $correlation_1 > correlation_2$ set $ewk=0$, otherwise set $ewk=255$.
- construct the extracted watermark ewk by assigning the determined bits for all blocks.

2.2. LSB technique

2.2.1 Embedding watermark

- Read the gray scale 512 X 512 host image.
- Read the gray scale 128 X 128 watermark image.
- Convert the gray scale watermark image into binary watermark image.
- Replace the bits of LSB-0 plane of host image with the binary values of watermark image, for $i=1$ to 128, $j=1$ to 128

$$ht(i, j) = wk(j) \quad (4)$$

Where ht is host image, wk is watermark image. e) After replacing the LSB-0 plane in the host image, watermarked image wkd is obtained.

2.2.2 Extracting watermark

- Extract the binary bits from LSB-0 plane of the watermarked image, for $i=1$ to 128, $j=1$ to 128

$$ewk(i) = wkd(i, j) \quad (5)$$

Where ewk is extracted bits of watermark image, wkd watermarked image.

- reshape and convert the binary watermark image to gray scale to get extracted watermark image.

2.3. Discrete Wavelet Transform (DWT) technique

2.3.1 Embedding watermark

- Read the gray scale 512 X 512 host image.
- Read the gray scale 128 X 128 watermark image.
- Carry out the DWT on the host image to support its division into the sub bands referred to as LL1, HL1, LH1, and HH1.
- save the LH1 sub-band.
- Carry out the DWT on the watermark image to support its division into the sub-bands referred to as LL2, HL2, LH2 and HH2.
- Save the LL2, HL2, HH2 sub-bands.
- Incorporate the LH2 sub band of watermark within the LH1 sub-band by utilizing the specified embedding equation, i.e., for $i=1$ to 128, $j=1$ to 128

$$LH1(i, j) = LH1(i, j) + \alpha * LH2(i, j) \quad (6)$$

Where wk is LH2 sub band of watermark image, α is the embedding strength factor.

- Conduct the inverse DWT on the LL1, HL1, LH1, and HH1 sub-bands for the purpose of reconstructing the watermarked image, wkd .

2.3.2 Extracting watermark

- Implement the DWT on the watermarked image wkd to segregate it into the sub-bands designated as LL3, HL3, LH3 and HH3.
- Isolate the LH2 sub band of watermark from the LH3 sub-band utilizing the specified equation, i.e., for $i=1$ to 128, $j=1$ to 128

$$eLH2(i, j) = (LH3(i, j) - LH1(i, j)) / \alpha \quad (7)$$

Where $eLH2$ is sub band the extracted watermark, α is the embedding strength factor.

- conduct the inverse DWT on the LL2, HL2, $eLH2$, and HH2 sub-bands for the purpose of reconstructing the watermark.

2.4. DWT-DCT-QR technique

2.4.1 Embedding watermark

- Read the gray scale 512 X 512 host image.
- Read the gray scale 128 X 128 watermark image.
- Utilize the DWT on the host image to systematically partition it into the LL1, HL1, LH1, and HH1 sub-bands.
- Apply DWT on LH1 sub-band to decompose it into LL2, HL2, LH2, and HH2 sub-bands.
- Apply DCT on LH2 sub-band, $dcLH2$.
- Factorize $dcLH2$ using QR decomposition to get $q1$, $r1$.
- save $q1$ matrix.
- Execute the DWT on the watermark image to facilitate the breakdown into the sub-bands designated as LL3, HL3, LH3 and HH3.
- save LL3, HL3, HH3 sub-bands.
- Factorize LH3 using QR decomposition to get $q2$, $r2$.
- save $r2$ matrix.
- Embed the watermark in the $q1$ using equation, i.e., for $i=1$ to 64, $j=1$ to 64

$$q1(i, j) = q1(i, j) + \alpha * q2(i, j) \quad (8)$$

Where α is the embedding strength factor.

- Multiply $q1$ and $r1$ to obtain embedded $dcLH2$.
- Apply inverse DCT on $dcLH2$ to get embedded LH2 sub-band.

- o) Apply inverse DWT on HH2, HL2, embedded LH2, LL2 sub-bands to get embedded LH1 sub-band.
- p) Utilize the inverse DWT on the sub-bands HH1, HL1, embedded LH1, and LL1 to obtain the watermarked image wkd.

2.4.2 Extracting watermark

- a) Administer the DWT on the watermarked image featuring the watermark wkd to precisely divide it into the sub-bands designated as LL4, HL4, LH4 and HH4.
- b) Apply DWT on LH4 sub-band to decompose it into LL5, HL5, LH5, HH5 sub-bands.
- c) Apply DCT on LH5 sub-band, dcLH5.
- d) Factorize dcLH5 using QR decomposition to get q3, r3.
- e) Extract the q component of watermark from q3 using the equation, i.e., for $i=1$ to 64, $j=1$ to 64

$$ewk(i, j) = (q3(i, j) - q1(i, j)) / \alpha \quad (9)$$

Where α is the embedding strength factor.

- f) Multiply ewk and r2 to obtain eLH3.
- g) Apply inverse DWT on LL3, HL3, eLH3, LL3 sub-bands to get grayscale watermark image.

3. Results and Discussion

Primary criteria for digital picture watermarking are imperceptibility, resilience, and embedding capacity. Imperceptibility in watermarking is the extent to which the embedded watermark falls outside the range of human visual or auditory perception. Robustness refers to the capacity of a watermarking approach to efficiently safeguard owners' data from any unauthorized modifications and must exhibit resilience. The imperceptibility of the watermarking technology can be assessed by an evaluation of the integrity of the watermarked image. An evaluation of the robustness of the watermarking technique may be performed through the quantification of the quality of the extracted watermark. The IQA metrics calculated in this research work are PSNR [10], NCC [11]. PSNR is computed for watermarked image to evaluate Imperceptibility, NCC is computed for extracted watermark to evaluate robustness.

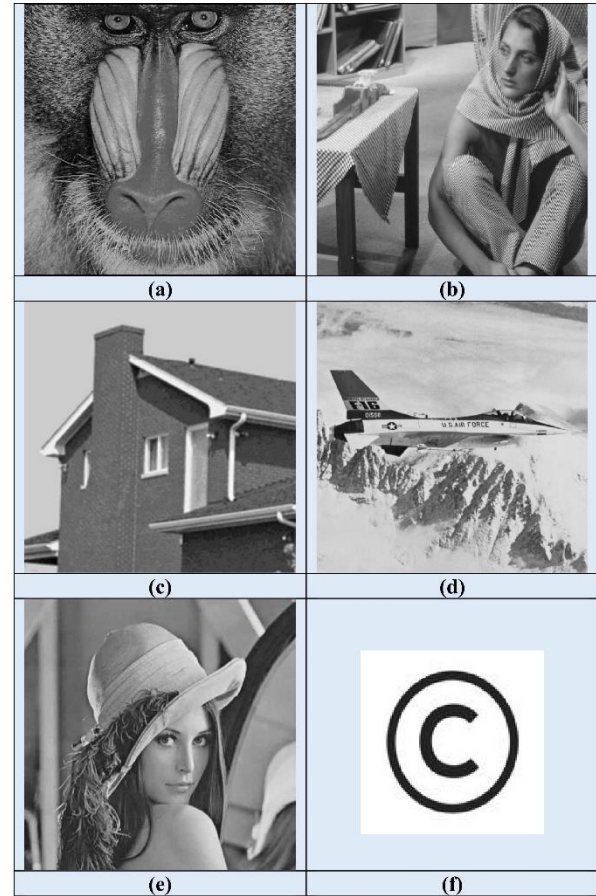


Figure 1. Host images and watermark image (a) Baboon (b) Barbara (c) House (d) Jet Airplane (e) Lena (f) copyright

$$PSNR \quad (10)$$

$$= 10 \log_{10} \frac{L^2 MN}{\sum_{i=1}^M \sum_{j=1}^N (w(i, j) - a(i, j))^2}$$

$$NCC = \frac{\sum_{i=1}^M \sum_{j=1}^N w(i, j) a(i, j)}{\sum_{i=1}^M \sum_{j=1}^N (w(i, j))^2} \quad (11)$$

Where L is the maximum dynamic range of image, $M \times N$ are the dimensions of the image, $w(i, j)$ is the reference/original watermark image, $a(i, j)$ is the watermarked/ extracted watermark image. Ideally the values of PSNR of watermarked image and NCC of extracted watermark must be high for maximum Imperceptibility and robustness respectively. Five 512 x 512 grayscale test images were used as host images. They are Baboon, Barbara, House, jet airplane, Lena. A 128 x 128 'Copyright' logo grayscale image were used as watermark image. About 12 attacks on the watermarked image are simulated. Figure 1. shows the Host images, watermark utilized in watermarking techniques implemented. Figure 2. shows attacked host images. The simulations were carried out in MATLAB 2018 software. They are (SPN- salt and pepper

noise, SN- Speckle noise, GN-Gaussian noise, PN-Poisson noise in [12]), (HE- Histogram equalization, GF- Gaussian filter, MF-Median filter in [13]), (SHPN- Sharpen, Motion BLR- Blur in [14]), (RO- Rotate, FP- Flip in [15]), CP- Compression [16]. Noise attacks are Salt and Pepper, Speckle, Gaussian, Poisson attacks with $\sigma = 0.5$, filtering attacks are Gaussian, Median filters with kernel size 5×5 , 3×3 respectively, motion blur attack with 3×3 kernel size, rotation attack with rotation angle 90 degrees, sharpening attack with aperture size and strength 1, compression attack is JPEG compression (Q=95%).

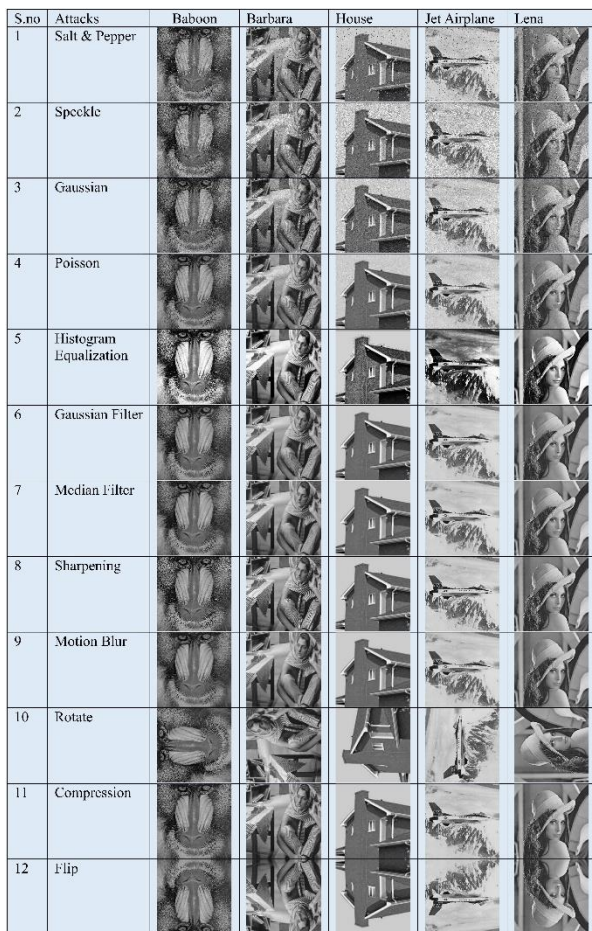


Figure 2. Attacked Host Images

Results were calculated in the following sequence. Initially, a particular watermarking technique is implemented to get both image that bears a watermark and the isolated watermark. Secondly, the PSNR, NCC metrics were calculated for Unscathed image that bears a watermark and the isolated watermark from Unscathed watermarked image, respectively. Thirdly, the watermarked image is attacked with 12 types of attacks. Fourthly, watermark Visual representations were derived from the 12 attacked watermarked images. Finally, NCC were calculated for each

watermark image obtained. The same procedure is repeated for 5 test images and 4 watermarking techniques.

Figure 3. and (Figure 4.-Figure 7.) Illustrates the extracted watermarks under No attacks and attacks from ADW, LSB, DWT and DWT-DCT-QR watermarking techniques, respectively. Table 1. Shows the PSNR values of watermarked images obtained from different watermarking techniques. Table 2., Table 3. Shows the NCC values of extracted watermarks obtained from different watermarking techniques under no attack and attacks respectively. Table 3. contains average NCC value of NCC values obtained for 12 attacks.

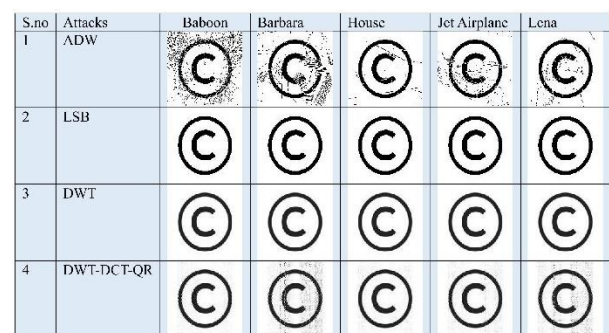


Figure 3. Extracted watermarks under No attacks

In (Table 1.-Table 3.) the numbers 2.1, 2.2, 2.3,2.4 indicate ADW, LSB, DWT, DWT-DCT-QR watermarking techniques respectively, Avg indicates Average.

3.1 Imperceptibility

The PSNR values for the four watermarking techniques—ADW, LSB, DWT, and DWT-DCT-QR—illustrate their differing imperceptibility levels when embedding watermarks. The ADW technique consistently yields the lowest PSNR, with an average of 32.74826 across all images. This narrow range (32.7461 for Lena to 32.7546 for Baboon) underscores its focus on robustness over imperceptibility, resulting in noticeable visual degradation.

Table 1. PSNR of watermarked images obtained from watermarking techniques

Images	PSNR (2.1)	PSNR (2.2)	PSNR (2.3)	PSNR (2.4)
Baboon	32.7546	63.1781	58.0933	54.2098
Barbara	32.7462	63.2389	58.0933	51.4886
House	32.7482	67.2715	58.0933	74.7120
Jet Airplane	32.7462	63.1765	58.0933	58.0400

Images	PSNR (2.1)	PSNR (2.2)	PSNR (2.3)	PSNR (2.4)
Lena	32.7461	63.0220	58.0933	60.1720
Avg PSNR	32.7482	63.9774	58.0933	59.7244

Table 2. NCC values of watermark extracted under No attacks from watermarking techniques

Images	NCC (2.1)	NCC (2.2)	NCC (2.3)	NCC (2.4)
Baboon	0.8855	0.9993	0.9998	0.9912
Barbara	0.9225	0.9993	0.9998	0.9692
House	0.9905	0.9993	0.9998	0.9910
Jet Airplane	0.9727	0.9993	0.9998	0.9880
Lena	0.9832	0.9993	0.9998	0.9767
Avg NCC	0.9508	0.9993	0.9998	0.9832

Table 3. Average NCC values of watermark extracted under Attacks from watermarking techniques

Images	Avg NCC (2.1)	Avg NCC (2.2)	Avg NCC (2.3)	Avg NCC (2.4)
Baboon	0.7657	0.5891	0.8766	0.9254
Barbara	0.8079	0.6107	0.9393	0.9219
House	0.8562	0.7649	0.9423	0.9047
Jet Airplane	0.8362	0.6332	0.9351	0.9121
Lena	0.8563	0.6858	0.9426	0.9049
Avg NCC	0.8245	0.6567	0.9272	0.9138

Conversely, the LSB technique achieves the highest average PSNR of 63.9774, reflecting minimal distortion in watermarked images. Particularly for the "House" image, it achieves a peak PSNR of 67.2715, showcasing exceptional imperceptibility, while other images maintain PSNR values above 63, making it ideal for applications where visual quality is crucial. The DWT technique, with a consistent PSNR of 58.0933 across all images, demonstrates uniform watermark embedding at fixed frequency sub-bands. Although it offers a balance between imperceptibility and robustness, its PSNR is notably lower than that of LSB, indicating some sacrifice in visual quality. The DWT-DCT-QR technique averages 59.72448 PSNR, with values highly dependent on image complexity, ranging from 51.4886 for the

textured "Barbara" image to an impressive 74.7120 for the simpler "House" image. This variability highlights its adaptability but also reveals the need for optimization to enhance performance consistency across diverse images. Overall, while LSB excels in imperceptibility, DWT-DCT-QR shows potential for improvement in specific scenarios, and ADW remains suited for robustness-focused applications.

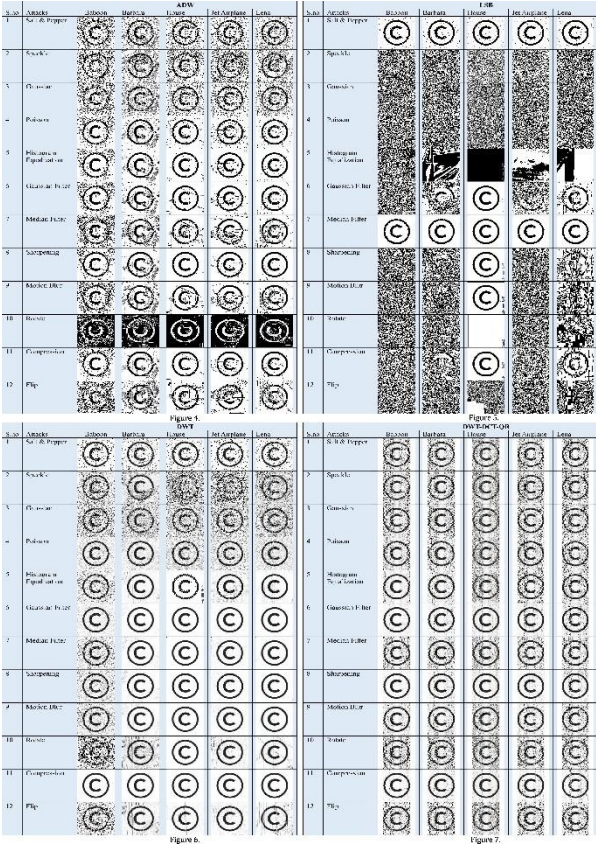


Figure 4., Figure 5., Figure 6., Figure 7., show the Extracted watermarks from ADW, LSB, DWT, DWT-DCT-QR techniques under attacks respectively

3.2 Robustness

Under no attacks, the DWT technique achieves the highest average NCC of 0.9998, showcasing its exceptional ability to preserve watermark fidelity consistently across all images. The LSB method closely follows with an average NCC of 0.9993, demonstrating equally strong performance with minimal variability, making it highly reliable for precise watermark extraction. The DWT-DCT-QR technique, with an average NCC of 0.98322, shows high overall accuracy but exhibits variability, particularly for complex images like "Barbara" (0.9692) and "Lena" (0.9767), indicating sensitivity to image content. In contrast, the ADW technique achieves the lowest average NCC of 0.95088, with values ranging from 0.8855 (Baboon) to 0.9905

(House), reflecting its focus on robustness over exact fidelity in ideal conditions. While DWT leads in maintaining watermark integrity, LSB offers comparable reliability, and DWT-DCT-QR shows potential for improvement in handling diverse image structures.

Under attacks, the DWT technique demonstrates the highest robustness with an average NCC of 0.927212, consistently preserving watermark integrity across all images. Its performance is particularly notable for "House" (0.94231) and "Lena" (0.94265), underscoring its effectiveness in handling distortions. The DWT-DCT-QR method follows closely with an average NCC of 0.913824, showcasing strong resilience and competitive performance, especially for complex textures like "Baboon" (0.9254). The ADW technique achieves moderate robustness with an average NCC of 0.824518, maintaining stable performance across images, with its best results observed for "Lena" (0.85633) and "House" (0.85628). In contrast, the LSB technique exhibits the lowest robustness with an average NCC of 0.656792, significantly affected by attacks, particularly for "Baboon" (0.58914) and "Jet Airplane" (0.63321). These results indicate that while DWT offers the best overall robustness, DWT-DCT-QR provides comparable performance, ADW ensures moderate resilience, and LSB is less suited for attack-prone environments.

4. Conclusion

Among the four watermarking techniques analysed, the LSB technique excels in imperceptibility, achieving the highest PSNR values with minimal visual distortion, making it ideal for applications prioritizing visual quality. However, its robustness under attacks is limited, as reflected by its lower NCC values in such scenarios. The DWT technique strikes an effective balance, offering the highest robustness both with and without attacks, while maintaining competitive imperceptibility. The DWT-DCT-QR method demonstrates adaptability and strong robustness, particularly for complex images, but exhibits variability in both imperceptibility and watermark fidelity, indicating room for optimization. Conversely, the ADW technique prioritizes robustness over imperceptibility, achieving moderate resilience but at the cost of noticeable visual degradation. Overall, DWT emerges as the most robust method, LSB as the most imperceptible, and DWT-DCT-QR as a promising candidate with potential for refinement to improve

consistency and performance across diverse image structures.

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