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# Watermarking in Frequency Domain A Review

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**Abstract**: ***Watermarking is the process of embedding data called a watermark into a multimedia object such that watermark can be detected or extracted later to make an assertion about the object. The multimedia object may be an audio, image or video. The aim may be to provide data authentication, data integrity, copyright and so on, depending upon the need. Watermarking can be done either in spatial domain or in frequency domain, the latter one proves to be more efficient than working in the spatial domain. Working with the watermarking in frequency domain requires transformation tools and in this paper we will discuss these various techniques giving more stress on wavelet transforms.***

**Keywords:** watermarking, FFT, DCT, DWT.

## 1. Introduction

The rapid expansion of the Internet and the overall development of digital technologies in the past years have sharply increased the availability of digital multimedia content. Though digital media provides various efficient facilities like easy distribution, reproduction and manipulation of digital media, but at the same time it had raised the new challenge in front of the research community to give new techniques to protect unauthorized reproduction of digital media. The solution for this problem is to add the visible or invisible structure to digital media which is to be protected from illegal duplication. In digital image watermarking, a watermark is embedded into a cover image in such a way that the resulting watermarked signal is robust to certain distortion caused by either standard data processing in a friendly environment or malicious attacks in an unfriendly environment. The watermark is later recovered from the watermarked image and detected for image authentication.
The basic idea behind transform domain techniques like FFT, DCT, Z-transform and DWT is to transform the media, because working in one domain is better than the other. For example a musical sound can be better visualized and understood as frequency variations rather than voltage fluctuations. The transform domain coefficients are then modified in one of the several possible ways to embed the watermark and finally inverse transform is applied to obtain the watermarked digital media.

## 2. Problems with Spatial Domain

Spatial domain techniques work directly on the source image by dealing with pixel intensities while embedding watermark. Though the technique is less complex, easy to implement, more capacitive but has flaws as:

- Poor robustness.
- Can be easily attached.
- Watermark can be removed or destroyed easily by applying common signal processing operations like data compression.
- Characteristics of human perception are not taken into account.

## 3. Frequency Domain Watermarking

Transforming the signal from spatial to frequency domain is more appropriate for watermarking because of its following properties.

- Statistical independence between pixels is obtained.
- Inverse transformation evenly spreads the watermark over host image giving tough times to attackers.
- Takes HVS into consideration.
- Watermark can be embedded into significant area of host image, thus providing robustness against several attacks.
- Cropping a serious threat to spatial domain hardly impacts in transformation domain.

### 3.1 Discrete Fourier Transform (DFT)

The Fourier transform provides a representation of functions defined over an infinite interval and having no particular periodicity, in terms of a superposition of sinusoidal functions [1].The DFT of a function provides a quantitative picture of the frequency content in terms of magnitude and phase. This is fundamental in the processing and analysis of signals. Some of the characteristics of DFT are:

- It is robust against various geometric attacks like rotation, translation, cropping and so on.

- Scaling of a signal in spatial domain causes inverse scaling in Fourier domain. It means as spatial scale expands, the frequency scale contracts and amplitude increases to keep area constant [2].

$$F[f(at)] = 1/a \times f^{'}(\omega / a) \quad (1)$$

a=constant, t= time, ω=2πν

- The translation property of Fourier Transform has no effect on the amplitude of the output signal, however phase gets altered. This property is mathematically defined as:

$$F[f(t+a)] = e^{ia\omega} f^{'}(\omega) \quad (2)$$

- Rotating the image through an angle in spatial domain causes the Fourier representation to be rotated through the same amount [3].
- The DFT magnitude of a signal can be significantly altered without affecting the perceived quality of an image, because the Human Visual System is less sensitive to magnitude distortion as compared to the phase alteration.

[4] have proposed a robust and imperceptible watermarking algorithm using FFT (Fast Fourier Transformation). The coefficients of both cover image and watermark image are computed by applying FFT. A scaling factor is defined that is suitable for invisible watermarking. The FFT coefficients of both images are modified using the following equation.

$$I_w(i,j) = I(i,j) + \beta W(i,j) \quad i,j = 1,2,3,4 \quad (3)$$

Watermark is extracted using the following equation.

$$W(i,j) = \frac{[I_w(i,j) - I(i,j)]}{\beta} \quad (4)$$

$$i,j = 1,2,3,4$$

Where, $I$ = Original image
$W$ = Watermark image
$I_w$ = watermarked image and
$\beta$ = Embedding factor.

[5] have modified the Fourier magnitude coefficients of cover image ($m_{ij}$) by making the use of pseudo-noise. The entire watermark ($w_{ij}$) is modulated by a binary pseudo-noise matrix (P) that serves as a key for retrieval process. The watermark is embedded into the magnitude coefficients of cover image in Fourier domain as,

$$m_{ij} = m_{ij} + a \times P_{ij} \times W_{ij} \quad (5)$$

Where amplitude factor a, is a constant determining signal strength. The extraction process does require original cover image. The average of magnitude coefficients at each point of the watermarked image is calculated. The difference between the calculated and the actual value is then divided by the pseudo-noise initially used in the embedding process. The proposed algorithm shows high robustness to the distortion like blurring and lossy compression.

### 3.2 Discrete Cosine Transformation (DCT)

DCT is another powerful transformation technique that transforms an image into three frequency bands: higher, middle and lower frequency bands. Literature reveals that the middle frequency band is optimum to watermarking and it does not degrade the perception quality of watermark images. The steps involved in any technique which is based on DCT are as follows [6]:

1) Divide the entire image into 8x8 sized non-overlapping blocks.
2) Take the DCT of each block of size 8x8.
3) Apply a block selection criteria based on the knowledge of Human Visual System (HVS).
4) Use some coefficient selection criteria for embedding.
5) Embed the watermark by modifying the selected coefficients.
6) Take the inverse DCT of each block.

Most algorithms are classified based on step 3 and 4.That is, the main difference between most of the algorithms is that they differ in either block selection criteria or coefficient selection criteria. The various characteristics of DCT are as:

- The output of DCT is a sequence of real numbers provided the input to the function is real.
- DCT forms the heart of JPEG image compression.
- The sensitivity of HVS to DCT basis images has been extensively studied resulting in a default quantization table [2].

[7] have found that error inevitably exists in DCT and inverse DCT processes which influence both the insertion and extraction of steps watermarking. To overcome this they have proposed a spatial domain watermarking algorithm based on DCT. The watermark image is converted into a one-dimensional binary sequence, which is embedded into 8*8 pixel matrix of the host image as follows: if embedded data is ‘1’, every pixel of host image matrix is incremented by ‘1’,the 255 pixel value is excluded to prevent color changes due to overflow. The pixel value is not changed if the embedded data is ‘0’. This process is repeated until the whole watermark is embedded. This algorithm evenly changes each and every pixel of the host image which is beneficial to keeping the watermarked image quality. On extraction the respective sum of host image blocks (sum1) and watermarked image blocks (sum2) is computed. If (sum2 – sum1) > 0, then embedded watermark is ‘1’, otherwise ‘0’. This step repeats until entire watermark data is extracted. [8] introduces the image fusion for watermark security, embedding the watermark with the help of DCT. The watermark is embedded into the cover image, the output watermarked image is then fused with the original cover image giving a synthesized image. This synthesized contains three data elements, watermark, original cover image and watermarked image. The system does not require original image at the detection process, offers high security and high image quality as well. [9] propose an image watermarking algorithm based on constraints in the DCT. The algorithm proposed in this study has two processing steps: the selection of certain block sites in the image and the DCT constraint embedding. The selection of the block sites is done by a Gaussian network classifier. Two different methods for embedding the constraints in the DCT coefficients. The first method embeds a linear constraint in the selected DCT coefficients and the second method defines circular regions in the DCT coefficient space. The simulation results suggest that the proposed algorithms generate watermarks which are able to resist at certain JPEG compression ratios and to filtering.

### 3.3 Discrete Wavelet Transformation

The basic concept behind DWT is that of wavelets. Wavelets are small waveforms with an average value of zero which can start and stop at any point on the axis where we wish. Wavelet analysis breaks the original signal into shifted and scaled versions. It has been found that any image formed on the retina of eye splits into separate frequency bands. Each band of frequency is then separately processed by the Human Visual

System. Similarly multi-resolution decomposition of an image by DWT divides the image into separate frequency bands of approximately equal bandwidth. Hence the independent processing of these bands by DWT makes the process of imperceptible marking very effective. DWT applied on an image divides it into four sub-images, 1 approximation component and 3 detail components. The approximation component as LL and detail components as LH, HL, and HH. LL contains the information about low frequency components of an image like smooth areas, while HH component contains high frequency parts of an image like sharp edges. LH and HL bands contain intermediate frequency bands of an image. LL band can be further decomposed to get the next level wavelet coefficients and the process of decomposition continues till the desired fine details about the image are obtained.

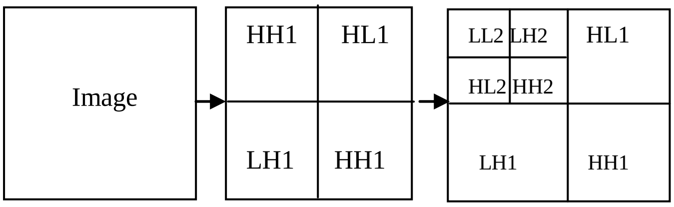


**Figure 1:** 2-level decomposition of an image by DWT

The wavelet transform have several advantages over other transforms.

- DWT provides an excellent spatial localization and multi-resolution analysis of digital images.
- It follows HVS characteristics more precisely.
- With scaling and shifting properties of transformation, access to very fine details and trends in a particular waveform is possible.
- The computational efficiency of DWT is very much better *O(n), n* represents length of the signal.

**3.3.1 Coefficient Selection Criteria [11]**

i. Modification to the low frequency coefficients can cause visible artifacts in the spatial domain. Hence, low frequency coefficients should be avoided.
ii. High frequency coefficients are not suitable because they are removed during JPEG compression.
iii. The best location to embed the watermark is the mid frequency.

[10] have proposed a DWT-DCT based blind watermarking algorithm for copyright protection. The original image is decomposed by level-1 DWT, the approximation component is then further decomposed by DCT. On the other hand the watermark is scrambled with Arnold transformation. The scrambled watermark is now embedded into the mid frequency DCT coefficients obtained previously. If watermark bit is ‘1’, then,

$$X = X + \alpha \times pn0 \qquad (6)$$

If watermark bit is ‘0’, then,

$$X = X + \alpha \times pn1 \qquad (7)$$

Where, X = mid frequency coefficients of DCT, α = intensity factor, pn0 and pn1 are pseudo-random sequences containing data elements equal to the number of X and are generated using some key. The proposed algorithm is robust against typical attacks such as Gaussian white noise, median filtering, cropping, resizing, and JPEG compression.

[12] have proposed a robust watermarking technique for copyright protection using 3-level DWT. Both the cover image and watermark image are decomposed by DWT up to 3-levels. The watermark is embedded into the low approximation components using alpha blending technique. Here low approximation components of decomposed host image and watermark image are multiplied by respective scaling factors and then added as,

$$WMI = (k \times LL3) + (q \times WM3) \qquad (8)$$

LL3 and WM3 are low frequency coefficients of host image and watermark image respectively, obtained by 3-level DWT, k, q are scaling factors.

[13] have proposed a robust and a secure watermarking algorithm using DWT and cat mapping. The watermark is encrypted using cat mapping before embedding into the desired frequency band. Cat mapped watermark is embedded into the wavelet channel C of 3- level decomposed host image by applying the equation.

$$C(n,m) = \begin{cases} C(n,m), 0 \le n \le \frac{N}{8} - M \ \& \ 0 \le m \le \frac{N}{8} - M \\ K \times M(n - \frac{N}{8} + M, m - \frac{N}{8} + M, otherwise \end{cases} \qquad (9)$$

$$0 \le n \le \frac{N}{8}, 0 \le m \le \frac{N}{8}, 0 \le K \le 1$$

Following equation is used for watermark extraction.

$$W(n,m) = K^{-1} \times C\left(n + \frac{N}{8} - M, m + \frac{N}{8} - M\right) \qquad (10)$$

$$0 \le n \le M, 0 \le m \le M$$

[14] have proposed DWT, DCT and SVD (singular value decomposition) based hybrid watermarking algorithm. Both host image and watermark image are first decomposed by DWT level-1, the HH bands are further decomposed by applying DCT, giving coefficient matrix H for cover image and coefficient matrix W for watermark image. H is mapped into 4 quadrants q1, q2, q3, and q4 using zigzag scanning. Apply SVD on each quadrant to get S1, S2, S3, and S4 respectively. SVD is also applied on W to get Sw. S1, S2, S3, and S4 are modified using following equation:

$$S_{ii} = S_i + \alpha \times S_w \qquad (11)$$
$$i = 1,2,3,4$$

Coefficients from zigzag scanning are mapped to original position matrix H*, on which DCT is applied giving $HH^*$. Watermarked image is obtained on applying inverse DWT on LL, LH, HL, and $HH^*$

## 4. Conclusion

In this paper we discuss three transformation techniques, Fourier Transformation, Cosine Transformation and Wavelet Transformation. It can be found that Wavelet Transformation is better for watermarking as compared to other two transformations. The reasons are efficient multi-resolution decomposition and HVS characteristics of DWT.

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