Analysis of Multiscale Transform based Digital Image Watermarking for Multimedia Files

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Abstract--- Watermarking technique used in areas of text, image, audio and video for the purpose of copyright protection, broadcast monitoring, data authentication and identification of owner of multimedia documents in network environments. This paper informs about multiple transforms of watermarking technique DFT(Discrete Fourier Transform), DCT (Discrete Cosine Transform), DWT (Discrete Wavelet Transform), SVD (Singular value decomposition) and compare to each other based on its application. This paper also explain, false position problem in SVD and Rounding error problem which presently exists in the frequency domain with their solutions.

Keywords: Digital watermarking, DFT, DWT, DCT, SVD, Rounding Error Problem and classes of watermarking based on application and characteristics.

I. INTRODUCTION

Digital watermarking has a suitable technique for identifying the source, creator, distributor or authorized consumer of a document or an image. It can also detect a document or an image that has been illegally distributed or modified.

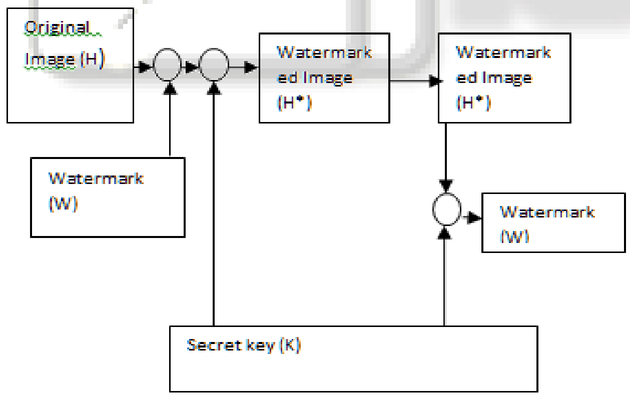

Fig. 1: General digital watermarking system

A watermark message W is embedded into a media message, which is defined as the host image H. The resulting image is the watermarked image (H*). In the embedding process, a secret key K that is, a random number generator is some time involved to generate a more secure watermark. The watermarked image (H*) is transmitted along communication channel. The watermark can later be detected or extracted by the recipient. Imperceptibility, security, capacity and robustness are among the many aspects of watermark design. The embedded watermark should be robust with invariance to intentional (e.g. Noise) or unintentional (e.g. Image enhancement, cropping, resizing or compression). Many researchers have been focusing on security and robustness, but rarely on watermarking capacity [1]. Another scheme is the use of keys to generate random sequences during the embedded process. In this scheme, the cover image (host image) is not needed during the watermark detection process [2, 3]. Based on embedding purpose watermarking can be classified into three categorized:-

A. *Robust Watermark:*

If any alteration attacks (image enhancement, filtering, noise or compression) on the watermarked data results in no change in watermark value then this is considered under the robust watermark.

B. *Semi-fragile Watermark:*

Semi-fragile watermarks are designed for detecting any unauthorized modification, while at the same time allowing some image processing operations.

C. *Fragile Watermark:*

In this watermarking system embedded watermark can be easily destroyed in host data. It is mainly used for authentication of multimedia data.

In this paper 8 sections, section 1 is the introduction of digital image watermarking and section 2, 3, 4 we have an analysis of the spatial domain, transform domain, and SVD domain based on its application. Section 8, we have discussed the rounding error problem and try to suggest a solution.

II. WATERMARKING DOMAIN

In general embed watermark in three types of domain:-

A. *The spatial domain*
B. *The frequency domain(or Transform domain)*
C. *Singular Value Decomposition*

A. *The spatial domain*

In spatial domain we can replace the pixels in the host image with the pixel in watermarked image [4].But disadvantage in this domain computer program may easily detect the inserted watermark.

B. *The frequency domain(or Transform domain)*

In the frequency domain we can replace the coefficients of a transformed image with the pixels in the watermarked image. The frequency domain transformations most commonly used are discrete cosine transform, discrete Fourier transform, and discrete wavelet transform. This kind of embedded watermark is difficult to detect. However, its embedding capacity is low and large amount of data distort the host image significantly. The watermark must be smaller than host image. In the present technique of watermarking some researcher [5,6] used SVD domain so we have tried to explain what is SVD and why it's used in watermarking approach.

C. Singular Value Decomposition:

SVD decomposes a given matrix A as,

$$A=U.S.V^T$$

Where, U and V are orthogonal matrices of size M × M and N × N, respectively. S is a diagonal matrix of size M × N, with the diagonal elements representing the singular values which are the square roots of the Eigen value of both AA^T and A^TA. Column of the matrix U (the left singular vectors) is the eigenvector of AA^T, while columns of the matrix V (the right singular vectors) are the eigenvector of $A^T A$.

Note that the singular vectors of an image specify the image "geometry", while the singular values specify the "luminance" (energy) of the image.

It is found that slight variations in the singular values do not affect the visual perception of the quality of the image. This property based on psycho-visual effect that allows embedding the watermark bits in the original image through minor modification of the singular values of the original image. Note that the use of singular vectors for information hiding more appropriate than using the singular values. Singular value decomposition is a general linear algebraic technique, where a given matrix (image in this case), is digitalized such that most of its signal energy is localized in few singular values.

Recently singular value decomposition (SVD), a new transform for watermarking has been introduced and the first algorithm has been proposed by Liu et al. [18] in 2002. The main feature of SVD-based image watermarking is the stability of singular values, which contain most of the image energy. In false positive problem it was possible to extract a watermark which was not actually the embedded one [19]. The problem of rightful ownership has been addressed by few authors through hybrid DWT-SVD based algorithms [20].

Scaling Property:

If the singular values of A of size m × n are $s_1, s_{2,} \ldots s_K$, then $|a|(s_1, s_{2,} \ldots s_K) = (s_1, s_{2,} \ldots s_K^*)$.

Translation Invariance:

The original image A and its rows or columns interchanged image have the same singular values.

Rotation Invariance:

If P is unitary and rotating matrix, the singular values of P.A (rotated matrix) will be same as that of A.

Transposition Invariance:

If $A\,A^T u = \lambda 2$ u then, $A^T A$ v = $\lambda 2$ v , so that A and A^T have same singular values.

Energy Localization:

Singular value decomposition is a general linear algebraic technique, where a given matrix is a diagonal side such that most of its signal energy is localized in few singular values.

[5] In SVD based watermarking, many approaches are possible. A general approach is to apply SVD to whole cover image, and modify all the singular values to embed the watermark data. A main property of SVD based watermarking is that the huge of the modified singular values change very little for most types of attacks.

Parameters	***Spatial Domain***	***Transfom Domain***	***SVD***
Robustness	Fragile	More Robust	Semi-Fragile
Computation Cost	Low	High	High
Perceptual quality	High Control	Low Control	Better Control
Capacity	High (depending on the size of the image)	Low (1/16 of the host image)	High (depending on the size of the image)
Application	Mainly authentication	Copyright protection	Authentication and Copyright protection

Table. 1: Comparison Between Watermarking Technique

Table 1 represents the summary report of the spatial domain, transform domain and SVD based on the watermarking parameters.

III. DIGITAL WATERMARKING CLASSIFICATION BASED ON CHARACTERISTICS

Digital watermarking technologies divided into five classes based on the characteristics of embedded watermarks:

A. Blind versus Non-blind
B. Perceptible versus Imperceptible
C. Private versus Public
D. Robust versus Fragile
E. Spatial domain based versus Frequency domain based

A. Blind versus Non-blind

A watermarking technique is said to be blind if it does not require access to the original data to recover the watermark. Advantage of blind watermarking is more popular because it decreases the overhead of cost for memory storing original data [2]. A watermarking technique is said to non-blind if the original data are needed for the extraction of the watermark. Advantages of Non-blind watermarking is more robust than blind watermarking system [6].

B. Perceptible versus Imperceptible

A watermark is said to perceptible if the embedded watermark is intended to be visible. For example, a logo is inserted into a corner of an image. In contrast, an imperceptible watermark is embedded into a host image by sophisticated algorithms and is invisible by the naked eye.

C. Private versus Public

A watermark is said to be private if only authorized users can detect it. Private watermarking technique invests all efforts to make it impossible for unauthorized users to extract the watermark. In general, private watermarking techniques are more robust than public watermarking.

D. Robust versus Fragile

Robust watermarks are designed to survive intentional (malicious) and unintentional (non-malicious) modifications of the watermarked image. Robust watermarks are usually used for copy protection, to declare rightful ownership.

For the purpose of authentication, fragile watermarks are adopted to detect any unauthorized modification. The few modifications of the watermarked image will alter or destroy the fragile watermark [7].

E. Spatial Domain Based versus Frequency Domain Based

In the spatial domain, we can simply insert a watermark into a host image by changing the gray value of some pixels in the host image. This has advantages of low complexity and easy implementation, but the inserted information may be easily detected using computer analysis or could be easily attacked. We can embed the watermark into the coefficients of a transformed image in the frequency domain. The transformations include the discrete cosine transform, discrete Fourier transform and discrete wavelet transforms. However if we embed too much data in the frequency domain then image quality will be degraded significantly.

IV. CLASSIFICATION OF WATERMARKING BASED ON APPLICATION

Digital watermarking techniques embed hidden information directly into the media data. Watermarking technique categorizes into five classes based on their application:

A. Copyright protection watermarks
B. Data authentication watermarks
C. Fingerprinting watermarks
D. Copy control watermarks
E. Device control watermarks

A. Copyright Protection Watermarking

A watermark is invisibly inserted into an image that can be detected when the image is compared with the original. This technique for copyright protection is designed to identify both the source of the image as well as its authorized users.

B. Data Authentication Watermarks

Digital signatures make use of public key or asymmetric cryptography, in which two keys related to each other mathematically are used. The public key is available to anyone who wishes to conduct verification, but the private key is given to authorized persons.

C. Fingerprint Watermarks

Digital watermarking of fingerprint images can be applied to protect the fingerprint images against malicious attacks, can detect fraud fingerprint images, and can ensure secure transmission. It allows the copyright owner to trace pirates if the image is distributed illegally.

D. Copy Control Watermarks

IBM's Tokyo Research Laboratory (TRL) first proposed the use of watermarking technology for DVD copy protection in September 1996. Copy control information indicating a copy restriction level is added to the main data recorded on the digital medium.

E. Device Control Watermarks

Device control watermarks are embedded control access to a resource using a verifying device. A watermarking system embeds an authorization code in a signal and transmits it to a verifying device. For examples: Television or radio program.

V. DISCRETE FOURIER TRANSFORM

In 1800, French mathematician Joseph Fourier introduces Fourier series for the representation of the continuous time periodic signal. The signal can be decomposed into a linear weighted sum of harmonically related complex exponentials. This weighted sum represents the frequency content of a signal called the *spectrum*. When the signal becomes non-periodic, its period becomes infinite and its spectrum becomes continuous. An image is considered as a spatially varying function. Fourier transform decomposes image function into a set of orthogonal functionality, and can transform the spatial intensity image into its frequency domain.

If f(x, y) denotes a digital image in the spatial domain and F (u, v) denotes a transform images in the frequency domain, the equation of 2D Discrete Fourier transform as:

$$F(u,v) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\, exp\left[-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)\right] \quad (1)$$

For u=0, 1, 2, …M-1 and v=0,1,2,.. N-1. The inverse DFT can be represented as:

$$f(x,y) = \sum_{u=0}^{M-1}\sum_{v=0}^{N-1} F(u,v)\, exp\left[j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)\right] \quad (2)$$

The DFT can be used for phase modulation between the watermark image and its carrier, for dividing the image into perceptual bands to record the watermark. The DFT uses phase modulation instead of magnitude components to hide message so phase modulation has less visual effect. Phase modulations are more robust against noise attack. The number of complex multiplications and additions required to implement DFT is N^2. Its calculation performed using a method fast Fourier transforms [8], which is complexity $N\log_2 N$.

VI. DISCRETE COSINE TRANSFORM

DCT transforms an image into the frequency domain and perform quantization for data compression. In which separates part of image (or spectral sub-bands) of hierarchical importance with respect to image visual quality. The JPEG technology uses the DCT to compress images. The Fourier transform kernel is complex valued. The DCT is obtained by using only a real part of the Fourier complex kernel. If f (x, y) denotes image in the spatial domain and F (u, v) denotes an image in frequency domain then the equation of 2D DCT is:

$$F(u,v) = C(u)C(v)\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\cos\left(\frac{(2x+1)u\pi}{2N}\right)\cos\left(\frac{(2y+1)v\pi}{2N}\right) \quad (3)$$

Where if u=v=0, C (u) = C (v) = $\sqrt{\frac{1}{N}}$;

Otherwise, C (u) = C (v)= $\sqrt{\frac{2}{N}}$.

The inverse DCT can be represented as:

$$f(x,y) = \sum_{u=0}^{M-1}\sum_{v=0}^{N-1} C(u)C(v)F(u,v)\cos\left(\frac{(2x+1)u\pi}{2N}\right)\cos\left(\frac{(2y+1)v\pi}{2N}\right) \quad (4)$$

Fourier cosine transform inherits many properties of Fourier transform. Note- Visual artifacts introduced by wavelet coded images are less evident compared to DCT because wavelet transforms doesn't decompose an image into blocks for processing. At high compression ratios, blocking artifacts is noticeable in DCT as against wavelet transformed images.

Advantages	
DWT	**DCT**
It has a higher compression ratio.	Compression time is lower than DWT.
Allows good localization both in time domain and frequency domain.	Computing cost is lower than DWT.
Higher flexibility:-wavelet function can be freely chosen.	Complexity of DCT is less as compare to DWT.
Disadvantages	
Computing cost is higher.	Impossible to arrange the blocks.
The use of larger wavelet filters produces blurring and ringing noise close edge regions in images.	Undesirable blocking artifacts affect reconstructed image.
Longer compression time.	Does not perform efficiently for binary image.

Table. 2: Advantages And Disadvantages Of Dwt And Dct Based On Application

VII. DISCRETE WAVELET TRANSFORM

DFT and DWT, which represents a signal either in spatial domain or in frequency domain, but DWT is able to provide a representation for both spatial and frequency domain. It is used in JPEG 2000 compression.

Wavelets are functions that integrate to zero waving above and below the x axis. Similar sine's and cosines in Fourier transform, wavelet is used as the base function for signal and image representation. Base functions are obtained by expanding and translating mother wavelet ψ (x) by amounts sand τ, respectively:

$$\psi_{\tau,s\,(x)} = \left\{\psi\left\{\frac{x-\tau}{s}\right\}, (\tau, s) \in R \times R^{+}\right\} \quad (5)$$

The translation and dilation allow the wavelet transform to be localized in time and frequency. Also, wavelet basis functions can represent functions with discontinuities and spikes (develop) in a more compact way than sine's and cosines.

CWT can be defined as:

$$cwt_{\psi(\tau,s)} = \frac{1}{\sqrt{|s|}} \int x(t)\, \psi^{*}_{\tau,s}(t)^{dt} \quad (6)$$

Where ψ*τ, s is the complex conjugate of ψ*τ, s and x (t) is the input signal defined in the time domain.

To discredit the CWT, the simplest case is the uniform sampling of the time frequency plane. However, sampling more efficient by using the Nyquist rule:

$$N_2 = \frac{s_1}{s_2} N_1 \quad (7)$$

Where, N1 and N2 denotes the number of samples at scales s1 and s2, respectively, and s2 > s1. This rule means that at higher scales (lower frequencies), the number of samples can be decreased. The sampling rate obtained is the minimum rate that allows the original signal to be reconstructed from a discrete set of samples. Coefficients filters are classified into two types. One is working as a low pass filter, and the other is a high pass filter. These two types of coefficients are called *quadrature mirror filter*.

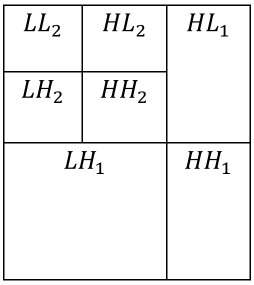

Fig. 2: Two level decomposition of image using DWT.

Here,
LL_1 are horizontal low pass and vertical low pass filters.
HL_1 are horizontal high pass and vertical low pass filters.
LH_1 are horizontal low pass and vertical high pass filters.
HH_1 are horizontal high pass and vertical high pass filters.
2D-DWT similar to 1D-DWT in which LL_1 band again divided into four sub-bands. [5,6] DWT provides enough information for analysis and synthesis of the original signal, with a significant reduction in the computation time.

Note- Wavelet transform can accurately model HVS (Human visual system) compare to other transforms like Discrete Fourier Transform (DFT) or Discrete Cosine Transform (DCT). This allows higher energy watermarks in regions where HVS is less sensitive. Embedding watermark in these regions allows us to increase robustness of watermark, with no much degradation of image quality.

Author Reference number	***Watermark Embedded in sub-bands***	***Level***	***Limitation***
[9]	All bands	N	Image quality degraded
[10]	Not specified	3	Time sufficiency for optimization
[11]	LH and HL bands	3	For only natural images
[12]	LH and HL bands	1	Not provide better security.

Table. 3: information of watermarking technique in dwts domain

DWT BASED BLIND WATERMARKS

Author Reference number	***Filter***	***Level***	***Embedding Type***	***Watermark Type***	***Watermark Embedded***
[13]	Quadra -ture Mirror	4	Additive	Gaussian vector	High pass bands
[14]	Not spec.	Multiple	Additive	Gaussian vector	High pass bands
DWT BASED NONBLIND WATERMARKS					
[15]	Not spec.	2	Additive	Gray scale image (cover image)	LL & HH sub-bands
[16]	Haar	2	Additive	Binary image	All bands
[17]	Daube-chies 10pt wavelet	3	Additive	Gray scale image	High pass band

Table. 4: DWT based blind and non-blind watermarking technique.

VIII. THE ROUNDING ERROR PROBLEM

The rounding error problem exists in frequency domain substitution watermarking. A recipient may confront the problem of correctly extracting the embedded watermark because the embedded message is changed due to modification of coefficient values. Generally the data after performing the DCT or DWT, followed by the inverse transformation such as inverse discrete cosine transform (IDCT) or inverse discrete wavelet transform, should be exactly the same as the original data. However, if some data in the transform image are changed, we will not obtain an image with all integers.

1	8	219	51
94	108	20	121
233	93	197	83
41	84	118	62

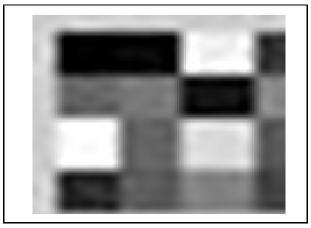

Fig. 3.(a) Grayscale value of original image; 3(b) Original image

383.25	-18.32	-40.25	92.28
-44.07	-60.89	-16.57	23.51
-91.25	-94.35	-96.75	-48.55
82.38	23.51	-30.20	-142.39

Fig. 3: (C) the coefficient value of transforming the image

Embed a watermark (W) into coefficient of the transformed image then obtain some coefficient of watermarked image change.

(W) Watermark	**Original Coefficient**	**Integer Part**	**Watermarked Coefficient**
1	-91.25	91	-92.77
1	-60.89	60	-61.63
0	-40.25	40	-40.35
1	92.28	92	92.40

Table. 5: Represents coefficient of original and watermarked images.

Some researchers suggest that the rounding technique be used to convert the real numbers to integers. Therefore, after adopting the rounding approach recipient wants to extract the watermark from the rounded image, unfortunately, the recipient cannot correctly extract the watermark from the location where it is embedded even through there is only one difference. In the above table 5, after watermark original coefficient -91.25 and -60.89 changes -92.77 and -61.63 respectfully. In this location when we convert real numbers to integers then obtain 92 and 61 which are actually differ. So in this way we embed watermark 1101 and extract watermark 0001 by recipients. The suggestion of the rounding error problem is instance of substitution watermarking using addition watermarking with respect to weight factor of watermark image or data.

IX. CONCLUSION

This paper informs about survey of digital image watermarking technique based on multiple transformations and tries to classify watermarking technique based on the application and characteristics (section 3 and 4). Section 2 we have discussed in the SVD, false position problem and solution of this problem hybrid DWT-SVD which is addressed by some researchers [20]. Section 8, we have discussed the rounding error problem which is available in frequency domain and try to suggest the solution of the rounding error problem.

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