DUAL TREE COMPLEX WAVELET TRANSFORM FOR DIGITAL WATERMARKING

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ABSTRACT
This paper presents, the multi-resolution watermarking method using dual tree complex wavelet transform (DT-CWT) for digital images. The multiscale DT-CWT coefficients of low and high frequency bands of the watermark is embedded to the most significant coefficients at low and high frequency bands of the DT-CWT of an host image, respectively. A multi-resolution nature of multiscale DT-CWT is exploiting in the process of edge detection. Experimental results of the proposed watermarking method are compared with the previously available watermarking algorithm wavelet transform. Moreover, the proposed watermarking method also tested on images attached by Discrete Cosine Transform (DCT) and wavelet based lossy image compression techniques.

KEYWORDS: Digital Watermarking; dual tree complex wavelet transform (DT-CWT); Security.

I. INTRODUCTION

The advent of the Internet has resulted in many new opportunities for the creation and delivery of content in digital form. Applications include electronic advertising, real-time video and audio delivery, digital repositories and libraries, and Web publishing. An important issue that arises in these applications is the protection of the rights of all participants. It has been recognized for quite some time that current copyright laws are inadequate for dealing with digital data. This has led to an interest towards developing new copy deterrence and protection mechanisms. One such effort that has been increasing the interest is based on digital watermarking techniques. Digital watermarking is the process of embedding information into digital multimedia content such that the information (which we call the watermark) can later be extracted or detected for a variety of purposes including copy prevention and control. Digital watermarking has become an active and important area of research, and development and commercialization of watermarking techniques is being deemed essential to help address some of the challenges faced by the rapid proliferation of digital content.

Watermarking techniques can be classified into various categories in various ways. It can be categorized according to either working domain or type of document or human perception or according to applications. Among these, categorizations by working domain and human perception have attracted main interest of the research community. The complete classification of watermarking techniques is shown in the Fig. 1. Among spatial and frequency domain techniques, spatial domain techniques are less complex but not robust against various attacks. Frequency domain techniques are robust as compared to spatial domain techniques. This is due to the fact that when image is inverse transformed, watermark is distributed irregularly over the image, making the attacker difficult to read or modify. In visible watermarking, the embedded watermark appears visible to the viewers on a careful inspection. In invisible-robust watermarking, watermark is embedded in such a way that it cannot be perceptually noticed and it can be recovered only with appropriate decoding/extracting mechanism.
In invisible-fragile watermarking, watermark is embedded in such a way that any small or big manipulation or modification of the image would destroy the watermark. If watermark detection/extraction process requires original or reference image then it is called an invisible robust private watermarking otherwise it is called invisible robust public watermarking. The invisible robust watermarking schemes that can be attacked by creating a counterfeit original image are called invertible watermarking schemes. If a unique watermark identifies the owner from all the distributed copies of media then technique is called source based watermarking technique and is desirable for ownership identification or authentication. On the other hand, if each distributed copy has a unique watermark identifying the particular buyer then technique is called destination based watermarking technique. Generally, it is used to trace the buyer in the case of illegal reselling.

![Classification of Watermarking Techniques](image)

Hwang et al. (1999) [1] have presented a watermarking scheme employed in spatial domain using hash functions. Djurovic et al. (2001) [2] have proposed fractional Fourier transform based watermarking scheme for the multimedia copyright protection. After decomposing image via FRFT, transformation coefficients are reordering in non-increasing sequence and the watermark is embedded in the middle coefficients. Ching et al. (2001) [3] have proposed a watermarking algorithm that is robust to RST distortions. The watermark is embedded into a one-dimensional (1-D) signal obtained by taking the Fourier transform of the image, resampling the Fourier magnitudes into log-polar coordinates, and then summing a function of those magnitudes along the log-radius axis. Barni et al. (2001) [4] proposed a watermarking algorithm operating in the wavelet domain. Performance improvement with respect to existing algorithms is obtained by means of a new approach to mask the watermark according to the characteristics of the human visual system (HVS). Manuel et al. (2002) [5] have proposed an analytical approach to pilot-based synchronization algorithms for data hiding in still images. A representative algorithm belonging to the family of those exploiting a regular structure in the spreading sequence is chosen for study. Zhang et al. (2003) [6] proposed an image watermarking scheme is developed using the tree-based spatial-frequency feature of wavelet transform. Adnan et al. (2003) [7] proposed the MPEG-4 compressed domain video watermarking method is proposed and its performance is studied at video bit rates ranging from 128 to 768 kb/s. The spatial spread-spectrum watermark is embedded directly to compressed MPEG-4 bit streams by modifying DCT coefficients. Wong et al. (2003) [8] proposed three blind watermarking techniques to embed watermarks into digital images for different purposes. The watermarks are designed to be decoded or detected without the original images. Wang et al. (2004) [9] proposed a wavelet-tree-based...
blind watermarking scheme for copyright protection. The wavelet coefficients of the host image are grouped into so-called super trees. The watermark is embedded by quantizing super trees. Feng et al. (2005) [10] have proposed a blind digital image watermarking algorithm using Fractional Fourier Transform (FRFT) and the energy distribution of two-dimensional signal at different FRFT domain is discussed. In this technique, multiple chirps are used as watermark which is embedded in the spatial domain directly, and detected in the FRFT domain. Yu et al. (2006) [11] proposed a digital watermarking embedding and detecting algorithm for image is presented, which uses the chirp signal as a watermark and embeds in the Fractional Fourier Transform (FRFT) domain of the image, and the watermark position and the transform order are used as the encryption keys. With the help of the property of the impulse characteristic in the FRFT domain for chirp signal, the watermark can be detected conveniently. Yuxin et al. (2006) [12] have proposed invisible watermarking scheme for digital images, where the watermark is embedded using the block based lapped orthogonal transform (LOT). The embedding process follows a spread spectrum watermarking approach. Prayoth et al. (2007) [13] have attempt to develop image watermarking algorithms which are portable to a variety of applications such as copyright protection, fingerprinting and identification. Zheng et al. (2010) [14] Proposed the watermarking system in multi-wavelet domain. And also, a multi-wavelet transform based JND digital watermarking algorithm. By calculating the texture measures of the multi-wavelet coefficients in the low frequency, the JND calculation model has been improved. Xuehua (2010) proposed the digital watermarking and its application in image copyright protection [15]. Xinge et al. (2010) [16] proposed an effective method for copyright protection of digital products against illegal usage, watermarking in wavelet domain has recently received considerable attention due to the desirable multi resolution property of wavelet transform. In general, images can be represented with different resolutions by the wavelet decomposition, analogous to the human visual system (HVS). Tetsuya et al. (2011) have proposed the blind watermarking algorithm which does not need to refer any original data in the watermark extraction process. They also discuss the analogy between the proposed watermarking scheme and CT-CDMA communication systems based on complete complementary codes [17]. Barni et al. (1998) [18] proposed as a solution to the problem of copyright protection of multimedia data in a networked environment. Kokare et al. [19] used the decomposition scheme based on rotated complex wavelets, which yields improved retrieval performance. Spatial domain methods are less complex and not robust against various attacks as no transform is used in them. The basic idea behind spatial domain methods is the modification of pixel intensities while embedding watermark. Transform domain methods are robust as compared to spatial domain methods. This is due to the fact that when image is inverse transformed, watermark is distributed irregularly over the image, making the attacker difficult to read or modify [15]. The basic idea behind transform domain methods is to transform the media by the means of Fourier Transform(FT), Discrete Cosine Transform(DCT) [18], Fractional Fourier Transform [2,10,11] Wavelet Transform [4,6,7,9] etc. Then, the transform domain coefficients are altered to embed the watermark and finally inverse transform is applied to obtain the watermarked digital media. The organization of the paper as follows: In section I, a brief review of Digital Watermarking and related work is given. Section II, presents a concise review of Complex Wavelet Transform. Section III, presents the watermarking schemes. Experimental results and discussions are given in section IV. Based on above work conclusions are derived in section V.

II. COMPLEX WAVELET TRANSFORM

Real DWT has poor directional selectivity as shown in Fig. 2 and Fig. 3 and it lacks shift invariance. It is found that both the above problems can be solved effectively by the complex wavelet transform (CWT) [19] by introducing limited redundancy into the transform. In CWT, filters have complex coefficients and generate complex output samples. However, a further problem arises here because perfect reconstruction becomes difficult to achieve for complex wavelet decomposition beyond level 1, when the input to each level becomes complex. To overcome this, Kingsbury [19_20] have recently developed the DT-CWT, which allows perfect reconstruction while still providing the other advantages of complex wavelets.
2.1 DT-CWT

The 1-D DT-CWT decomposes a signal $f(t)$ in terms of a complex shift and dilated mother wavelet $\psi(t)$ and scaling function $\phi(t)$

$$f(t) = \sum_{j,l} s_{j,l} \phi_{j,l}(t) + \sum_{j,l} c_{j,l} \psi_{j,l}(t)$$

Where $s_{j,l}$ is scaling coefficient and $c_{j,l}$ is complex wavelet coefficient with $\phi$ and $\psi$ complex:

$$\phi = \phi + i\phi, \quad \psi = \psi + i\psi.$$  The $\psi$ and $\psi$ are themselves real wavelets: the complex wavelet transform is combination of two real wavelet transforms. Fig. 4 shows that the implementation of 1-D DT-CWT.

The 2-D DT-CWT can be implemented using separable wavelet transforms like 2-D wavelet transform. Impulse responses of six wavelets associated with 2-D complex wavelet transform is illustrated in Fig. 5. These six wavelet sub-bands of the 2-D DT-CWT are strongly oriented in $\{+15^\circ, +45^\circ, +75^\circ, -15^\circ, -45^\circ, -75^\circ\}$ direction and captures image information in that direction. Frequency domain partition of DT-CWT resulting from two level decomposition is shown in Fig. 6.
III. WATERMARKING SCHEME

3.1 Watermark Embedding

In the embedding part shown in Fig. 4, the original image and the watermark are first decomposed using Multiscale DT-CWT. Then, the Multiscale DT-CWT coefficients \( W_{\text{low}} \), of the low-resolution representation of the watermark \( W \), are embedded in the largest Multiscale DT-CWT coefficients \( I_{\text{low}} \) of the low-resolution representation of the original image \( I \), in the following way:

\[
I_{\text{low}}(\text{low}) = I_{\text{low}}(\text{low}) + \alpha W_{\text{low}}(\text{low})
\]

Spectrum analysis of the images reveals that most of the information in image is located in this low-resolution representation, which represents the smooth parts of the image. It is also known that human eyes are very sensitive to small changes in smooth part of the image. However, with the appropriate choice of the scaling parameter \( \alpha \), the invisibility of the watermark could be adjusted. Conversely, in case of possible attacks, the low-resolution representation of the watermark will still be preserved within the low-resolution representation of the image, which makes the watermark robust.

Other coefficients of the watermark are embedded in the higher frequency components of the image, which represent the edges and textures of the image. Using above Eq. (2) either will produce watermarked image that is not robust to image operations that perform low pass filtering (for small values of \( \alpha \)) or will create visible defects in the images (for larger values of \( \alpha \)). So in order to increase the robustness of the watermark, following equation is used:

\[
I_{\text{low}}(\text{high}) = I_{\text{low}}(\text{high}) + \beta W_{\text{low}}(\text{high})
\]

Since human eyes are not sensitive to small change in the edges and the textures of the image, invisibility of the watermark is kept. The watermarked image is obtained by applying inverse

Fig. 6: Frequency domain partition in DT-CWT resulting from two level decomposition.

Fig. 7: 2-D dual-tree complex wavelet transform
Multiscale DT-CWT to the coefficients $I_{\text{arc}}$. The watermarked image may then be subject to any number of distortions due to intentional or unintentional image processing operations.

### 3.2 Watermark Extraction

In the decoding process shown in Fig. 4, DTC of the suspected image $\tilde{I}$ and of the original (unwatermarked) image is performed. Multiscale DT-CWT coefficients of the low-resolution representation of the extracted watermark are obtained as:

$$\overline{W}_{\text{arc}}(\text{high}) = \frac{1}{\alpha} \left[ \frac{I_{\text{arc}}(\text{high})}{I_{\text{arc}}(\text{high})} - 1 \right]$$

and wavelet coefficients in other frequency subbands as:

$$\overline{W}_{\text{arc}}(\text{low}) = \frac{1}{\beta} \left[ \frac{I_{\text{arc}}(\text{low}) - I_{\text{arc}}(\text{low})}{I_{\text{arc}}(\text{low})} \right]$$

With inverse Multiscale DT-CWT of $\overline{W}_{\text{arc}}$ the extracted watermark $\overline{W}$ is obtained.

### 3.3 Similarity measurement

The extracted watermarks can be compared with original watermark subjectively. Beside subjectively judgment for the watermark fidelity, we have defined an objective measure of similarity between the original watermark and the extracted watermark in the following way:

$$\text{SIM} = \sum_{i} \sum_{j} W(i,j) \overline{W}(i,j)$$

For instance, applying any image processing operation to the watermarked image that performs lowpass filtering (compression, resizing), will result in loss of multiscale DT-CWT coefficients in higher frequency bands of the watermark. In this case, multiscale DT-CWT coefficients in lower frequency subbands to be used to determine whether suspected image contains watermarks.

### IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

For evaluation of the proposed method, the image Lena of size 256x256 is used as test image (Fig. 9 (top left)), and image pattern of size 256x256 (Fig. 9 (top right)) is used as watermark. A two level multiscale DT-CWTs of the test image Lena and one level multiscale DT-CWT of the watermark is obtained. Choice of $\alpha = 0.045$ and $\beta = 0.06$ seems to give the best results in sense of robustness versus visibility. Watermarked Lena images obtained with proposed watermarking method is shown in Fig. 9(b). It can be seen that there is almost invisible difference between the watermarked and the original image, thus proving that the requirement of watermark invisibility is satisfied. In following, some geometric manipulations and compressions are applied to the watermarked image in order to test algorithm robustness.

The wavelet transform based watermarking also implemented to compare the performance of the proposed method with the wavelet transform based watermarking. Fig. 10 (bottom right) extracted watermark using wavelet transform based algorithm. From Fig. 9 and 10, it is clear that the proposed method is showing better performance for watermark extraction.
4.1 Robustness to DCT and DWT based compression

Image compression can be considered as the most common signal processing operation performed on images. Resistance to this operation is good test for watermarking robustness. Since, DCT [21, 22] is base of current international standard for still image compression, JPEG, and since DWT [22] is expected to be base of up-coming image compression standard JPEG2000, resistance to DCT and DWT based compression schemes are investigated in this experiment. The MATLAB code is implemented by us is used for this purpose. The different compression ratios are chosen for this purpose. Extracted watermarks are shown in Fig. 11, suggesting that the proposed watermarking method is robust to lossy compression. Increasing the compression ratio leads to visible distortion of the image and digital watermarking becomes less meaningful. Even then, watermark could be detected with the proposed watermarking algorithm, if subjective and objective measurements are applied to low-resolution representation of the extracted watermark.

4.2 Robustness to resizing

In this experiment image is reduced to 50% of its original size. For this purpose MATLAB function “imresize” is used. In this process fine detail are lost since subsampling of the image requires a lowpass spatial filtering operation. In order to recover the watermark, reduced image using the same function is rescaled back to the same size of the original image. Fig. 12 shows the extracted watermark.
Fig. 9: Watermarking results of the proposed method (left top) test Lena image, (bottom left) the watermarked image, (right top) the watermark, (bottom right) extracted watermark ($SIM = 0.981$).

Fig. 10: Watermarking results of the wavelet transform method (left top) The test Lena image, (bottom left) the watermarked image, (right top) the watermark, (bottom right) extracted watermark ($SIM = 0.912$).
Fig. 11: Extracted watermarks of DCT compressed version of the watermarked image shown in Fig. 4 (left bottom): (a) with compression ratio 8:1, (b) with compression ratio 11.38:1 using proposed method and (c) and (d) using wavelet transform method.

Fig. 12: Extracted watermark of rescaled watermarked image shown in Fig. 4 (bottom left) where 50% reduction and enlargement is done.

V. CONCLUSIONS

In this paper, a watermarking method was presented using Multiscale DT-CWT. Experimental results demonstrated that the watermarked image based on proposed method is best compared to wavelet transform method. Moreover, proposed watermarking method is robust to DCT and DWT based lossy image compression schemes, and geometric manipulations like image resizing.

REFERENCES


AUTHORS

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