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Comparative Analysis of Wavelet Filters on Hybrid Transform Domain Image Steganography Techniques

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Abstract: Steganography is an important area of research in recent years involving a number of applications. Image steganography is the art of hiding secret information into a cover image. The modern secure image steganography presents a challenging task of transferring the embedded information to the destination without being detected. Transform domain methods hide messages in insensitive areas of the cover image which makes them more robust to attacks. DCT/DWT is used to transform cover image from spatial domain to frequency domain. The secret image or information is then embedded into the frequency domain coefficients. Different wavelet filters can be used for embedding secret image in these frequency components. This paper compares hybrid transform domain techniques for different Wavelet filters for embedding secret image into cover image. The algorithms are compared for Peak Signal to Noise Ratio (PSNR) which is a measure of the difference between the cover image and the stego image.

Keywords: Image Steganography; Discrete Cosine Transform (DCT); Discrete Wavelet Transform (DWT); Least Significant Bit (LSB); Coiflet filter (coif)1; Symmlet (sym2).

I. Introduction

Hiding secret data is of prime importance for security purposes. Multimedia is the key for achieving this, so, any of the media such as text, audio, video and image can be used to hide data for security. The formats that are more suitable are those with a high degree of redundancy. Image is a good cover medium for concealing secret data as it contains more redundant information. Image hiding, by Steganography, protects the data from illegal access by hiding the data into a cover image such that an unintended observer is not aware of the existence of the hidden data [1]. Steganography basically consists of three things: cover object (used to hide secret message), secret message to be embed, and stego object (cover object after hiding the secret data) [2]. As human eyes are not sensitive for identifying little changes in an image, this fact can be used for hiding data in an image. The paper is organized as follows: Section 2 is devoted to transform domain techniques for image steganography. Section 3 gives a brief introduction of the hybrid transform domain technique. Section 4 describes the various wavelet filters for hiding secret image into hybrid transform domain cover image. Section 5 compares and concludes various wavelet filters discussed in section 4.

II. Transform Domain Techniques

New algorithms keep emerging prompted by the performance of spatial domain techniques due to rapid development of information technology and by the need for enhanced security system. As seen in the spatial domain techniques, LSB modification of images is an easy technique to embed information, but these are highly vulnerable to even small cover modifications [3]. An attacker can simply apply signal processing techniques in order to destroy the secret information entirely [4]. Most robust steganography systems known today actually operate in some sort of transform domain. Transform domain methods hide messages in insignificant areas of the cover image which makes them more robust to attacks. Many transform domain variations exist. One method is to use the Discrete Cosine Transformation (DCT) as a technique to embed information in images; another would be the use of wavelet transforms. Transformations can be applied over the entire image, to blocks throughout the image, or there may be other variations. However, a trade-off exists between the amount of information added to the image and the robustness obtained.

Discrete Cosine Transform (DCT)

The two dimensional DCT is the heart of the most popular lossy digital image compression systems today. This method encodes the secret information in the frequency domain by modulating the relative size of two or more DCT coefficients in an image.

It is an orthogonal transform, which has a fixed set of (image independent) basis functions, an efficient algorithm for computation, and good energy compaction and with correlation reduction properties.

The 1D DCT of a 1*N vector s(j) is defined as:

$$S(k) = DCT(s) = \frac{C(k)}{2} \sum_{j=0}^{N} s(j) \cos\left(\frac{(2j+1)k\pi}{2N}\right) \quad (1)$$

$$C(k) = \begin{bmatrix} \sqrt{\frac{1}{N}} \; for \; \mathrm{n} = 0 \\ \sqrt{\frac{2}{\mathrm{N}}} \; \text{otherwise} \end{bmatrix} \quad (2)$$

$$s(k) = DCT^{-1}(S) = \sum_{j=0}^{N} \frac{C(j)}{2} s(j) \cos(\frac{(2j+1)k\pi}{2N}) \quad (3)$$

The DCT can be extended to the transformation of 2D signals or images [5]. This can be achieved in two steps: by computing the 1D DCT of each of the individual rows of the two dimensional image and then computing the 1D DCT of each column of the image. In digital image processing, the two dimensional version of DCT is used which is given as:

$$\mathrm{S(u, v)} = \frac{2}{\mathrm{N}} C(u)C(v) \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} s(x, y) \cos(\frac{\pi u(2x+1)}{2N}) \cos(\frac{\pi v(2y+1)}{2N}) \quad (4)$$

$$\mathrm{s(x, y)} = \frac{2}{\mathrm{N}} \sum_{u=0}^{N-1}\sum_{v=0}^{N-1} C(u)C(v) s(u, v) \cos(\frac{\pi u(2x+1)}{2N}) \cos(\frac{\pi v(2y+1)}{2N}) \quad (5)$$

Discrete Wavelet Transform (DWT)

A wavelet is simply a small wave which has its energy concentrated in time to give a tool for the analysis of transient, non-stationary or time varying phenomena. A signal can be better analyzed if expressed as a linear decomposition of sums of products of coefficients and functions. These set of coefficients are called the Discrete Wavelet Transform (DWT) of a signal [6]. DWT has spatial frequency locality, which means that if signal is embedded, it will affect the image locally. Also, they do not take into account the fact that different regions in an image may have different frequency characteristics.

The forward 2-D DWT can be implemented using a set of up-samplers, down-samplers, and recursive two-channel digital filter banks. There are many available filters, but the most commonly used are Haar Wavelet filters, and Daubechies filters. Important properties of wavelet filters in digital image compression are symmetry (used for avoiding artifacts at the borders), orthogonality (fat algorithm), regularity, and degree of smoothness.

When applying DWT on an image, four different sub-bands are obtained, which are LL, LH, HL, and HH as shown in figure 1.

1. LL: A coarser approximation to the original image containing the overall information about the whole image. Since human eyes are much sensitive to the low frequency part, this is the most important component in the reconstruction process.
2. HL and LH: They are obtained by applying the high pass filter on one coordinate and the low pass filter on the other coordinate.
3. HH: It shows the high frequency component of the image in the diagonal direction.

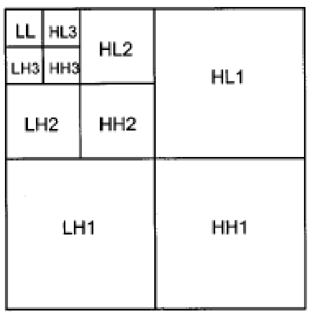

Fig. 1: Spectral Decomposition of a Cover Image in 2-D Plane

For 2-D images, applying DWT separates the image into a lower resolution approximation image or band (LL), as well as horizontal (HL), vertical (LH), and diagonal (HH) detail components.

With the DWT, the significant part of the spatial domain image exist in the approximation band that consists of low frequency wavelet coefficients and the edge and texture details usually exist in high frequency wavelet coefficients bands such as HH, HL, and LH. The human eyes are not sensitive to small changes in the edges and textures of an image but to the small changes in the smooth parts [7].

III. Hybrid Transform Domain Technique

DCT and DWT are the most commonly used algorithms. The DCT has high energy compaction property and requires less computational resources [8]. The energy compaction property of an algorithm refers to the ability to concentrate most important information signal into as much as few low frequency components. On the other hand, DWT is a multi-resolution transform technique and variable compression can be easily achieved. The main disadvantages of DCT are introduction of false contouring effects and blocking artifacts at higher compression, and, that of DWT is requirement of large computational resources. So the idea of exploring the advantages of both algorithms generates the idea of combining the two techniques. Such combination of two algorithms is referred as hybrid algorithm.

Both DCT and DWT transform domain techniques are robust in nature and one technique outweighs another with respect to some parameter of importance. So, instead of using only one technique hybrid transform domain technique can be used [9] [10]. This allows for better imperceptibility and payload in comparison to using a single technique. The block diagram and the algorithm for image steganography using the concept of hybrid transform domain are as shown:

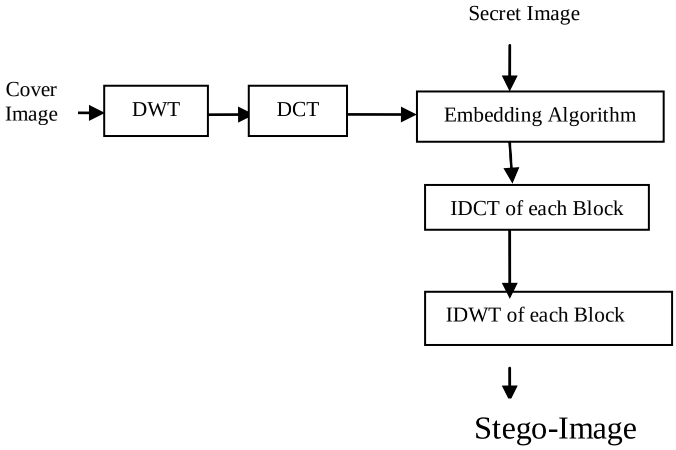

Fig. 2: Hybrid Transform Domain Technique for Hiding Secret Image in Cover Image

IV. Wavelet Filters

In applying DWT, a number of wavelet filters can be used. These filters are: Haar filter (db1), Daubechies series (dbN series where N is the order), symmlet filter series (sym2), and coiflet filter (coif1). Each of these filters decomposes the image into several frequencies. In Haar-DWT the low frequency wavelet coefficients are generated by averaging the two pixel values and high frequency coefficients are generated by taking half of the difference of the same two pixels.

V. Results and Comparison

In this section, effect of wavelet filters on the hybrid transform domain techniques is analyzed. The filters are changed in DWT transformation in DWT + DCT, DCT + DWT, and multistage DWT techniques and their effect on PSNR is evaluated. The values in the table are for PSNR.

Table 1: Effect of various DWT filters on hybrid domain techniques

Wavelet Filters	DWT + DCT	DCT + DWT	DWT + DWT
Haar (db1)	59.477	37.3910	54.00
Daubechies (db2)	59.5174	35.83	54.22
Daubechies (db10)	59.7002	35.41	54.61
Symmlet (sym2)	59.5174	35.83	54.22
Coiflet (coif1)	59.6521	38.77	55.70

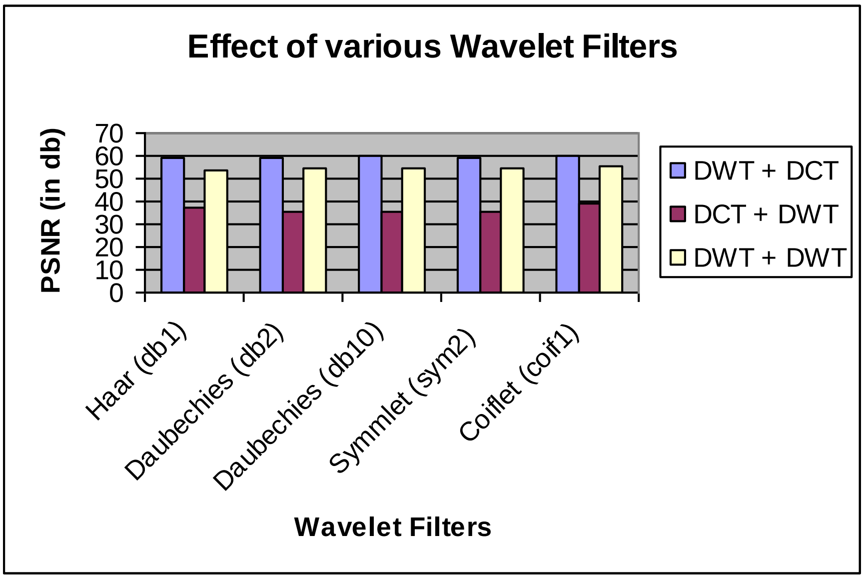

Fig 2: Graph showing effect of various wavelet filters

As shown in the table, for the three schemes used, Daubechies filter (db10) provides the best value of PSNR. Haar wavelet is the simplest one. Coiflets are discrete wavelets designed by Ingrid Daubechies. For images with large size, db10 provides the best PSNR. It has good frequency localization and is smooth in nature. For medium size images, coiflet and daubechies wavelet functions give best results. For the case of multistage DWT as two stages of DWT are used, the size of the image reduces with each stage of transform, resulting in a medium size image. So, coiflet filter gives the best PSNR of 55.70 and the result obtained using daubechies filter db10 is almost similar to it.

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