Image Steganogaraphy Based on Complex Double Dual Tree Wavelet Transform

Sushil Kumar and S. K. Muttoo

***Abstract*—In this paper we present an improved steganographic algorithm based on the modified LSB method in four different wavelet transform domains, viz, Wavelet (wavcdf97), Slantlet, Double Density Dual Tree Discrete Wavelet transform and Double Density Dual Tree Complex Wavelet, respectively. The characteristics of the Complex Wavelet Transform that provides shift invariance and offers better directional selectivity makes it a better choice for data hiding over the classical discrete wavelet transform. For achieving the security and robustness, the original message is first converted into binary cell array with the help of self-synchronizing variable length codes, viz., T-codes before the embedding. The use of T-codes does not only compress the message but also provides self-synchronization at decoding stage. The secret message so obtained is embedded in the insensitive high sub-bands obtained from the cover image after applying these transform. The metric used for evaluating the visual quality of stego-image is PSNR. The experimental results show that the dual tree complex wavelet transform is better option than the Wavelet, Wavelet-like transform, i.e., Slantlet transform and Double Density Dual Tree DWT for data hiding in terms of visual quality and embedding capacity, though poor to external attacks such as Gaussian.**

***Index Terms*—Steganography, DWT, SLT, DD DT DWT, DT CWT, T-codes, PSNR.**

I. Introduction

The discrete wavelet transform (DWT) is considered to be an important tool for data hiding techniques. There are applications that demand high capacity, e.g., in the advance research on network transmission security and lossless embedding such as in military, legal and medical imaging domains. There exists steganographic algorithm based on integer wavelet transform that provides better embedding capacity and better imperceptibility than the earlier used transforms such as DCT. DCT remained famous domain of embedding as it was the major compression technique in earlier JPEG compression technique. Wavelet transform replaced the DCT in the JPEG 2000 and also found to be better option than DCT in terms of embedding capacity and robustness. However, DWT lacks directional selectivity for diagonal features and shift invariance. The dual tree complex wavelet transform (DT-CWT) has a modest amount of redundancy, but it provides shift invariance and good directional selectivity. Kingsbury [1] introduced Dual-Tree Complex Wavelet Transform (DT-CWT) and Selesnick [2], [3] provided Double-Density DWT (DD DWT) and Dual-Tree DWT (DT DWT) for complex analysis. They have shown that DT-CWT has a modest amount of redundancy, but it provides shift invariance and good directional selectivity. The 2-D DT-CWT is based on two distinct scaling functions and two distinct wavelets, whereas Double-Density DWT is based on a single scaling function (low pass) and two distinct wavelets (high pass). On the application of 2-D DD DWT , the cover image is decomposed into nine sub-bands labeled LL, LH_1, LH_2, H_1L, H_1H_1, H_1H_2, H_2L, H_2H_1, H_2H_2, respectively. The Double Density Dual-Tree DWT (DD DT DWT) possesses simultaneously the properties of DT DWT and DD DWT. The structure of DD DT DWT consists of two oversampled iterated filter-bank that operate in parallel. Each row of the cover image is first subjected to 1-D DD DT DWT decomposition in which one is real decomposition that uses the real component of DD DT DWT and the other is an imaginary decomposition. After the 1-level decomposition we obtain four times wavelets than the ordinary 2-D DD DWT decomposition.

In this paper we propose a high capacity data hiding technique based on the four transforms, viz., Wavelet (wavcdf97), Slantlet, Double Density Dual Tree DWT and Double Density Dual Tree Complex Wavelet, respectively. We embed data into an insensitive Wavelet/Slantlet/DT-CWT sub-bands using the modified LSB method. The embedding capacity can reach to ¾ of the cover image (grayscale) in Wavelet and Slantlet domains and 6/7 and more of the cover image (grayscale) in DD DT_CWT domain. The proposed algorithms are implemented in Matlab 7.0 using 256 x 256 size images. Experimental results show that the DD DT-CWT method has not only higher capacity but also better visual quality than other three methods, viz., Wavelet (wavcdf97), Wavelet-like transform (i.e., Slantlet) and DD DT DWT. This proposed improved high capacity steganogrphic technique can be applied to e-government, e-business, e-law enforcement, military system and e-medical system.

The rest of the paper is organized as follows. In section II we discuss about the embedding domain. The proposed algorithm is summarized in Section III, while the experimental results are presented in Section IV. Conclusion and future scope are presented in Section V.

II. Embedding Domain

In designing steganographic algorithm, special consideration is given to the domain in which the embedding will take place. No doubt , frequency domain have shown to

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be a better option than the spatial domain for steganographic algorithms in terms of high capacity, visual quality and robustness [4], [5]. Some of the transform domains already used in steganography are Discrete Fourier Transform (DFT), Discrete Cosine Transform (DCT), Discrete (Haar/cdf(2,2)) Wavelet Transform (DWT), Directional transforms such Curvelets, Contourlets etc. and Wavelet-like Transforms such as Slantlet Transform (SLT). The contourlets are introduced by M.N. DO and M. Vetterli [6]. Navas et al. [7] have described data hiding approach based on contourlet in medical images.

The slantlet transforms were introduced by Alpert et al. [8] and are described explicity by Ivan selesnick [9]. Panda et al. [10] have shown that SLT possesses better energy compaction properties than DWT. Maitra and Chatterjee [11] have used SLT in the intelligent system for magnetic resonance brain image classification. Sushil Kumar and S.K.Muttoo [12]-[14] have also shown that SLT further provides a much better approximation of the Human Visual System (HVS) than the DWT. However, DWT and SLT have their inability to differentiate between opposing diagonal features, i.e., have poor directional selectivity and lack of shift invariance. Selesnick [15] has shown that Complex Wavelet Transform (CWT) has the advantage of excellent shift invariance at the cost of 2:1 redundancy for 2-D signals. The DT DWT not only overcomes the problem of poor directional selectivity in DWT, but can also discriminate between opposing diagonals with six different sub-bands oriented at 15^0, 75^0, 45^0, -15^0, -75^0, and -45^0.

The one of the major requirement of any steganographic algorithm is imperceptibility. So it is necessary to limit the distortion applied to each individual coefficient of the transform decomposition. One of the solutions suggested by researchers is the use of error correcting codes but it increases the size of message to be embedded. The other solution may be to find the encoding scheme that minimizes the bit conversion while embedding the secret message. This method increases the computations. One may also use visual tests such as Just Noticeable Distortion (JND) profile. In the proposed algorithm we have used Self-synchronizing variable length codes, T-codes which have shown to be a better encoding scheme than a popularly known Huffman's coding [16], [17].

III. Proposed Algorithm

We propose DD DT DWT/DD DT-CWT based embedding algorithm in which the secret message is embedded in the insensitive frequency coefficients using modified LSB approach. LSB steganography is the simplest steganographic technique used in popular steganographic tools such as S-Tools, Steganos and StegoDos, where embedding is done in the spatial domain. The sequential LSB has a serious security problem [18] whereas random or modified LSB in which secret message can be randomly scattered in stego-images provides an improvement over the steganographic security.

The basic idea of LSB embedding is to embed the message bit at the rightmost bits of pixel value so that the embedding method does not affect the original pixel value greatly. The formula for the embedding is as follows:

$$x' = x - x \bmod 2^k + b ,$$

where k is the number of LSBs to be substituted. The extraction of message from the high frequency coefficients is given as:

$$b = x \bmod 2^k$$

The proposed algorithm proceeds as follows:

Step1. Obtain the secret data by applying best T-codes to the given input text/message. An encoded key is generated.

Step2. Decompose the cover image low and sub-bands (viz., LL, HL, LH and HH) by applying 2-D DWT/SLT/DD DT DWT/DT-CWT.

Step3. Approximate/Normalize the frequency coefficients to integers using a threshold value, usually 0.8.

Step4. Embed secret data in the middle and high frequency bands (LH, HL and HH) using the modified LSB method.

Step5. Obtain the stego-image by taking the inverse transform to the modified image.

The extraction method is the reverse method of embedding algorithm. It consists of the following steps:

Input: stego-image, encoded-key, stego-key

Output: original message

Step 1. Decompose the stego-image into low and high sub-bands using the transforms Wavelet/Slantlet/DD DT DWT/DT CWT.

Step 2. Extract the secret message using the stego-key used in embedding technique

Step 3. Obtain the original message by decoding the secret message using T-decoding algorithm and encoding key.

IV. Experimental Results

The proposed algorithm is implemented in four domains, viz., Wavelet domain, Slantlet domain, DD DT DWT and DT-CWT domain. We have used 256 × 256 size images and results are obtained by running the algorithm in Matlab 7.0 software. The summary of the results obtained for some of the images is given in table I. Figure 1 shows the comparison between four transforms in terms of PSNR values vs BPP (bits per pixel) rate. The results obtained show that DT-CWT outperforms the other transforms in terms of visual quality and embedding capacity.

TABLE I: Comparison of DWT, SLT, DD DT DWT and DT-CWT Methods(message length=6000)

Image	Wavelet (wavcdf97) PSNR (db)	2-D Slantlet PSNR (db)	2-D DD DT-DWT PSNR (db)	2-D DT CWT PSNR (db)
I1	44.350043	53.601686	60.445225	63.436141
I2	44.134947	53.553464	60.493630	63.094094
I3	44.329890	53.524250	60.962041	63.672915
I4	44.489671	53.570887	60.587625	63.406725
I5	46.074744	53.603920	60.089842	65.069457
I6	46.528802	53.293788	61.391552	63.898702
I7	46.726047	53.629027	61.219253	63.934244

(I1. Peppers.jpg, I2. Tooth1.jpg, I3. Twins.small.jpg, I4. Cameraman.tif, I5. Zoneplate.png, I6. Arts.png, I7. Lena.jpg)

TABLE II: GAUSSIAN EFFECT (= 0.0001) TO ADDED TO STEGO-IMAGE

Stego-images (256 x256)	Wavelet (cdf9/7) PSNR(db)	2D-Slantlet PSNR(db)	DT-CWT PSNR(db)
I1	20.108805	8.762560	8.759325
I2	20.306677	5.995230	5.992800
I3	20.081485	5.639925	5.637624
I4	20.961504	5.639925	5.637624
I5	20.961504	4.303052	4.301257
I6	19.996496	5.273580	5.270624
I7	20.069980	5.751725	5.754153

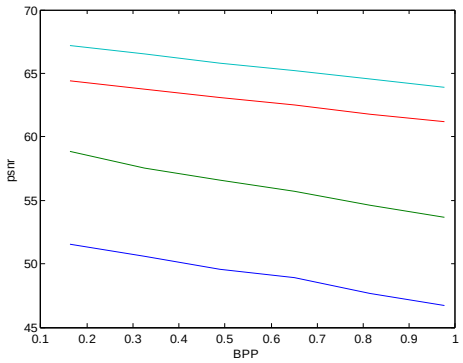

Fig. 1. Comparison of Wavelet (blue/bottom line), Slantlet (green/second line form bottom), Double Density Dual Tree Discrete Wavelet transform (red /third line from bottom), and Double Density Dual Tree Complex Wavelet transform (Top line) used in embedding algorithm based on LSB method in terms of psnr vs bpp with image='lena.jpg'

V. CONCLUSION

An improved steganographic algorithm based on the modified LSB technique using four different transforms, viz., DWT, SLT, DD DT DWT and DT-CWT is presented and compared in terms of visual quality and embedding capacity. The modified LSB method can be implemented conveniently and for high capacity data can be embedded using two or more LSBs bits per pixel. The disadvantage of the LSB method is that it is non-robust. Cleik et al. [19] have proposed Generalized-LSB data embedding that offers finer grain scalability along the capacity distortion curve. The purpose of this paper was to investigate comple wavelet transforms as an application to steganography and compare it with already known transform domains such as classical Haar or standard discrete wavelets and Wavelet-like transforms. The authors have also applied other techniques such as Thresholding technique and Wavelet-fusion technique [20]. Through experimental results they have observed that DT-CWT domain is superior than DWT or SLT domain in view of visual quality of stego-image and embedding capacity. Thompson et al. [21] have shown that DT-CWT domain is good robustness against several attacks such as Wiener filtering, Median filtering, Mean filtering, JPEG compression, and AWGN attacks for image watermarking based on Spread Spectrum and Quantization Index Modulation. We are working on finding a secure high capacity steganographic algorithm in the DT-CWT domain that is robust to common attacks such as low-pass filtering, JPEG compression and Gaussian noise.

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