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A Perceptual Reversible Data Hiding In Transform Domain

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ABSTRACT

Reversible data hiding is useful in some applications, like medical diagnosis and law enforcement, where it is critical to reverse the marked media back to the original cover media after the hidden data are retrieved for some legal considerations. In this paper we present a perceptual reversible data hiding (P-RDH) algorithm based on Contourlet Transform (CTT) and is compared with other transforms such as Bi-orthogonal discrete wavelet transform (CDF9/7), Discrete Slantlet Transform (SLT), Double Density Discrete wavelet transform (DD DWT) and Double Density Dual Tree Discrete wavelet transform (DD DT DWT). For embedding we use the Companding technique in conjunction with the self-synchronizing variable length code (T-codes) for compression of the message at pre-processing stage. It is observed that the order in which the different transforms perform in respect to imperceptibility for RDH is as follows: CDF9/7 < SLT < CTT < DD DT DWT < DD DWT. Further CTT and DD DT DWT based proposed algorithms show perfect structural similarity and good probable security between the original image and stego-image irrespective of its format.

Index terms – RDH, CTT, DD DT DWT, PSNR, SSIM, SSVLC

I. INTRODUCTION

A. Reversible Data Hiding

The reversible data hiding (RDH) technique enables cover image to be restored to their original form without any distortion after removing the hidden data from the stego-image. This technique is useful in many fields such as law enforcement, medical imagery, astronomical research, content authentication of multimedia data and so on. Yang and Lin [2] discussed two kinds of RDH schemes: *Perceptual quality schemes* that provides a perceived high quality in stego-images with a high embedding rate and *Robustness-oriented schemes* which are robust to image processing operations.

B. Journey to Transforms

It is known that wavelets and wavelet-like transforms (such as Slantlet transform (SLT) [11]) are good at representing discontinuities in one dimension or point singularities, but they fail to represent more type of singularities occurring in higher dimensions. Thus, transforms like Curvelets and Contourlets were proposed in 1999. Curvelet transform was defined in the continuum space R^2 and its discretization is a challenge when critical sampling is desired whereas Contourlet transform is proposed as an improvement on Curvelet transform using a double filter bank structure and possess all features of wavelets with a high degree of directionality and anisotropy.

The Contourlet transform employs Laplacian pyramids to achieve multiresolution decomposition and directional filter banks to achieve directional de-composition. It can represent a smooth contour with fewer coefficients compared with wavelet. However, due to downsampling and upsampling, the Contourlet transform is shift-variant, an undesirable property. One of the unique properties of Contourlet transform that makes it a suitable technique for steganography is that we could have any number of directional decompositions at every level of resolution. It is known that the wavelet transform divides the high frequency only into three sub-bands at each Level, whereas it is possible to divide the high frequency into more sub-bands in the Contourlet transform (shown in Fig.1). Further, the sub-bands in wavelet transform are correlated whereas the sub-bands in the Contourlet transform are linearly independent and hence uncorrelated. This property of Contoourlets could lead to more security in steganography, since there is lower possibility of detecting. It is also noted that the Contourlet transform is more suitable for data hiding applications as Contourlet gives more edges. Moreover, more data can be hidden in the high frequency regions without perceptual distortion of the original image

Selesnick [12] and Kingsbury [15] introduced Complex Wavelet Transforms (CWTs), a complex-valued extension to the standard DWT. They provide a high degree of shift-invariance and good directional selectivity. Dual tree complex wavelet transform (DT CWT) employs a dual tree of wavelet filters to obtain the real and imaginary parts of complex wavelet coefficients. After 1-level decomposition we obtain 4 times as many results as with ordinary 2-D Wavelet decomposition. Double-density dual-tree DWT (DD DT DWT) is a discrete wavelet transform that combines the double-density DWT and the dual-tree DWT. There are two types of 2-D DD DT DWT, 2-D DD DT real-oriented DWT and 2-D DD DT complex-oriented DWT, respectively. The first one is 2-times expansive and second is 4-time expansive to DD DWT. The 2-D DD DT Real DWT of a 2-D image is implemented by using two oversampled 2-D DD DWTs in parallel (Fig. 2). Then, for each pair of sub-bands we take the sum and difference, whereas 2-D DD DT Complex DWT gives rise to twice as many wavelets in the same dominating orientations as the 2-D DD DT Real DWT. This transform is implemented by applying four 2-D DD DWTs in parallel to the same input data with distinct filter sets for the tows and

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columns. We then take the sum and difference of the sub-band images. This results into 32 oriented wavelets.

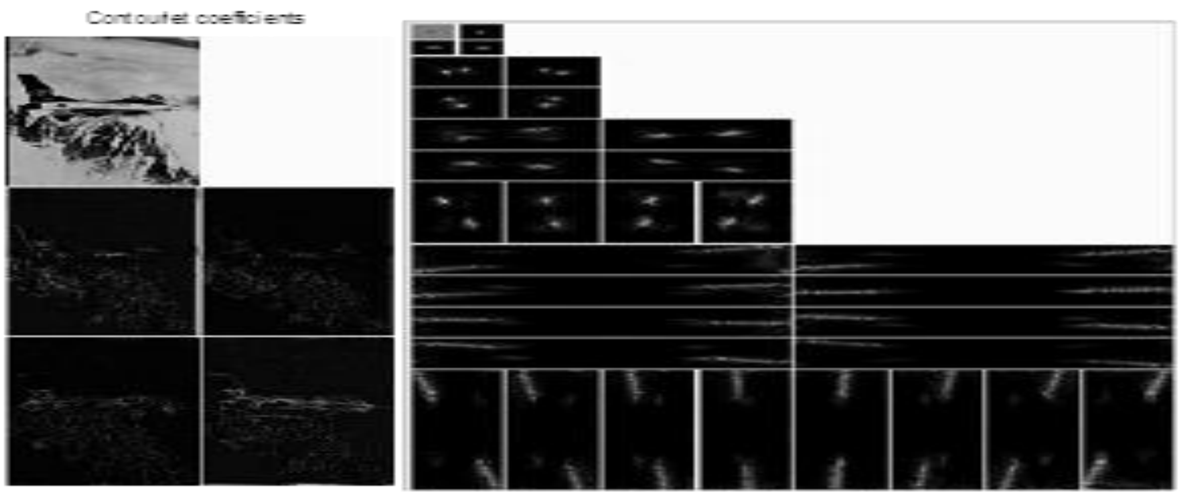

Figure 1. Contourlet decomposition of image: 'aeroplane.tif' at level-2 and level-4

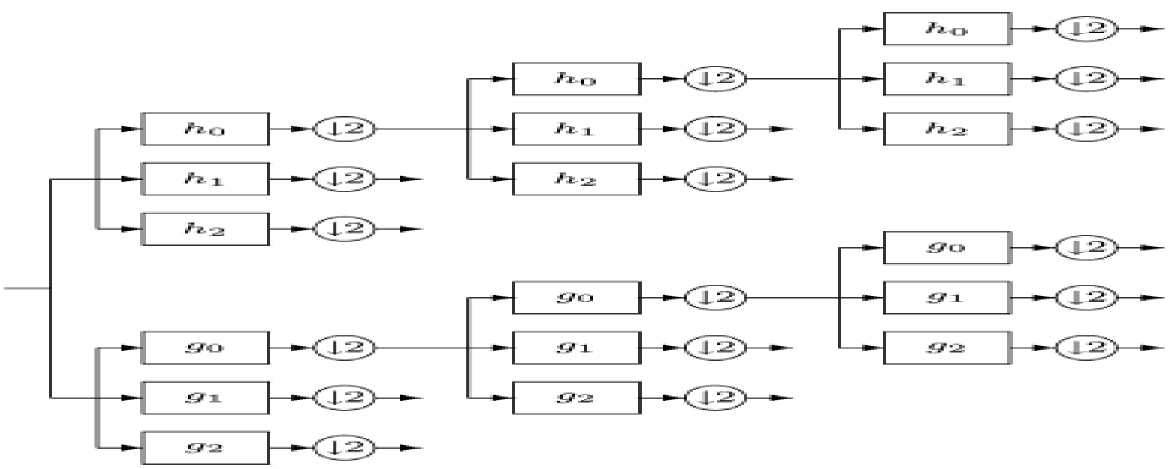

Figure 2. Decomposition process of 2-D DD DT (Real) DWT

II. Related Work

Honsinger et al [18] presented the lossless data hiding technique for fragile authentication that does not need much data to be embedded in a cover object. They used modulo-256 addition to embed the hash value of the original image for authentication, but their algorithm couldn't resist salt-n-pepper noise due to the many wrapped around pixel intensities.

Fridirch et al.[17] proposed the joint bi-level image experts group (JBIG) lossless compression technique that compress a set of selected features from a image to save space for data embedding.

Tian [20] proposed a high capacity RDH technique that expands the difference between two neighboring pixels to obtain redundant space for embedding a message. However, his scheme suffers from the location map problem that it is difficult to achieve capacity control. His algorithm was improved by Alattar [16] who used the DE of vectors of adjacent pixels to obtain additional space for embedding.

Xuan et al [22] proposed a lossless data hiding method based on IWT, which embeds high capacity data into the least significant bit-planes of high frequency wavelet coefficients whose magnitudes are smaller than a certain predefined threshold. Histogram modification is applied as a pre-processing to prevent overflow/underflow.

Ni et al. [19] proposed a RDH scheme that uses the histogram of the pixel values in the cover image to embed secret data into the maximum frequency pixels. However, their payload is quite limited because few images contain a large number of pixels with maximum frequency. Further, their scheme may lead to significant overhead and insufficient visual quality.

Yu and Wang [23] proposed an extended subsampling reversible data hiding method, which shifts the histogram of the differences between sub-images obtained through subsampling and embed data by modifying the pixel value according to embedding level.

Luo and Yin [25] have presented a new RDH scheme that utilizes the wavelet transform and better exploits the large wavelet coefficient variance to achieve high capacity and imperceptible embedding.

Yang and Lin (2012) have proposed a RDH method that uses the coefficient shifting (CS) algorithm with a mean predictor. Further, they present a robust RDH method using a variant of the CS algorithm that is based on the IWT domain to resist common image processing operations.

Yang, Lin and Hu (2012) have further presented a simple RDH scheme based on the IWT. By adjusting the coefficient values, data bits are effectively embedded into the low-high (LH) and high-low (HL) subbands of the IWT domain. Their experiments show that both the host media and secret message can be completely recovered, without distortion, if the stego-images remain intact. Moreover, the resulting perceived quality of the image is highly satisfactory, as is the hiding capacity.

Xian-ting Zeng et al. (2012) have proposed a lossless data hiding scheme by using dynamic reference pixel and multi-layer embedding. According to authors, their algorithm offers very high embedding capacity and low image degradation.

Zeng, L and Ping (2012) have proposed a lossless data hiding scheme based on the pixel difference histogram shifting to spare space for data hiding. Pixel differences are generated between a reference pixel and its neighbors on a pre-assigned block. They claim that the algorithm has very high embedding capacity and low image degradation.

Zhang [24] has proposed a RDH with optimal value Transfer. In his scheme, the optimal rule of value modification under a payload-distortion criterion is found by using an iterative procedure and the secret data as well as the auxiliary information used for content recovery, are carried by the differences between the original pixel-values and the corresponding values estimated from the neighbors. The estimation errors are modified according to the optimal value transfer rule and the original host content can be perfectly restored after extraction of the hidden data on receiver side.

III. Objectives & Overview Of The Proposed Mechanism

A. Objectives

In this paper, a perceptual reversible image steganography scheme based on CTT [3] in conjunction with self-synchronizing variable length codes (SSVLC), viz., T-codes is proposed. The similar work based on DWT, SLT, DD DWT and DD DT DWT can be seen in [5]-[10].
The embedding technique used in the proposed algorithm is one of the Companding technique, viz., *thresholding technique* described in next sub-section B. A brief summary about self-synchronizing variable length codes used at pre-processing level of the algorithm is given in sub-section C. The proposed algorithm is discussed in section IV. Experimental results and analysis of proposed pereptural reversible data hiding (P-RDH) algorthim are presented in section V.

B. Overview of the embedding technique

The embedding technique used in the proposed algorithm is one of the Companding technique, viz., *thresholding technique*.The Companding is the process of signal compression and expansion. The compression function, C maps large range of original signals x, into narrower range, y = C(x) whereas expansion, E is the reverse process of compression, x = E(y). After expansion, the expanded signals are close to the original ones. Assume the original signals are x. If the equation E[C(x)] = x is satisfied, then this kind of Companding could be applied into reversible data hiding.

A reversible Companding method for the lossless data hiding is given by Xuan [14]. In this method a threshold value is predefined. To embed data into a high frequency coefficient of sub-band HH, LH or HL, the absolute value of the coefficient is compared with T. If the absolute value is less than the threshold, the coefficient is doubles and message bit is added to the LSB. No message bit is embedded otherwise; however, the coefficients are modified as follows:

$$x' = \begin{cases} 2*x + b & \text{if } |x| < T \\ x + T & \text{if } x \geq T \\ x - (T-1) & \text{if } x \leq -T \end{cases}$$

where T is the threshold value, b is the message bit, x is the high frequency coefficient and x' is the corresponding modified frequency coefficients.

To recover the original image, each high frequency coefficient can be restored to its original value by applying the following formula:

$$x = \begin{cases} \lfloor x' \rfloor / 2 & \text{if } -2T < x' < 2T \\ x' - T & \text{if } x' \geq 2T \\ x' + T-1 & \text{if } x' \leq -2T+1 \end{cases}$$

C. Self-Synchronizing Variable Length Codes (SSVLCS)

Titchener[13] devised an algorithm for the construction of prefix free code words, known as T-codes. T-codes are generated by recursive T-augmentation of elements in an alphabet, e.g., suppose a binary alphabet S = {0, 1}. To obtain the first set of code words from S, we apply T-augmentation on it, i.e. we remove one of the elements from S and augment it with both the elements of set S. Suppose if we remove the element '0' from S, the new set, $S_{(0)}$ = {1, 00, 01}. In case we remove element '1 ' from $S_{(0)}$ and T-augment it, the new set obtained is $S_{(0,\ 1)}$ ={00, 01, 11, 100, 101}.Titchner [13] proposed the general formula as:

$$S^{(k)}{}_{(p)} = U\{ p^i[S-\{p\}]\}\ U\ p^{k+1} \quad (i=0, k)$$

where S is a finite alphabet, a string *p* Є *S* (called the *T-prefix)* and a positive integer *k* (called the *T-expansion parameter)*.

Gunther [4], in his thesis, has proved that T-codes possess inherent self-synchronizing property. They require anything between 1.5 to 3 characters to attain synchronization following a lock loss. This has been observed [10] that the popular Huffman codes, used as encoder, could be replaced by T-codes as the later not only provide best compression but also have self-synchronizing property useful at decoding stage for recovering the hidden message correctly.

IV. PROPOSED ALGORITHM

A. Embedding & Extraction Process

The proposed RDH algorithm based on CTT is shown in Fig.3. The embedding and extraction process are as follows:

Algo 1: Embedding

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Step1. First obtain the secret data by applying best T-codes as a source encoder to the given input text/message.
Step2. Apply pre-processing to prevent possible "overflow" during embedding, e.g. replacing the grayscale values 0 to 255 into 15 to 240 of cover image.
Step3. Consider 8-bit greyscale image and decompose it 5 sub-bands: one low-pass sub-band and 4 sub-bands for horizontal and vertical directions by applying 2-level CTT
Step4. Embed the secret data in the 4 high sub-bands obtained in the Step3
Step5. Obtain the stego-image by taking the inverse CTT of the modified image of Step4.

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Algo 2: Extraction

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Step1. Apply CTT to the stego-image
Step2. Extract secret data from the middle and high frequency sub-bands of CTT by inverse thresholding techniques.
Step3. Extract embedded secret data and recover the original image by reverse operation of the embedding.
Step4. Obtain the original message by T-decoding the secret data, with the help of encoding key.

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Just before the embedding (Step4 of Algo1), a normalization process (Hard thresholding method) to the Contourlet coefficients of selected sub-bands is applied. Further, using a threshold value, T (that represents the tradeoff between quality of the stego-image and its robustness against compression), the double values of Contourlet coefficients are converted to integer. After the secret data is embedded, the modified coefficients are converted to double values before applying Step5 to get the stego-image. The value of T is determined experimentally.

The comparative study of the proposed algorithm based on CTT is done with the same algorithm based on other transforms such as CDF 9/7, SLT, and DD DT CWT. The measures used to compare the given algorithm with them are discussed in next subsections.

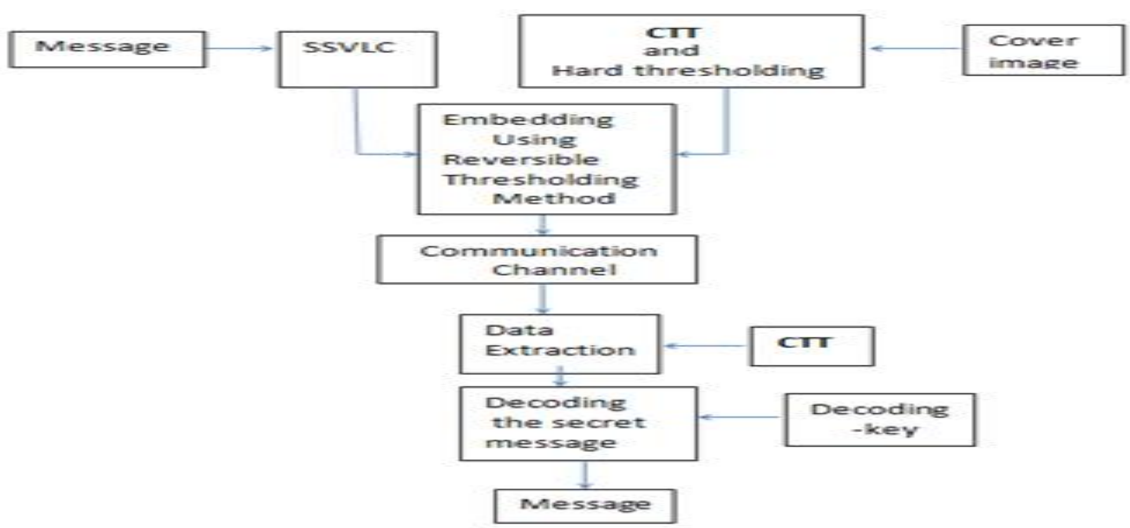

Figure3. Embedding process and Extraction process

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V. Performance Evaluation

The proposed *Algo 1* is tested using number of standard gray-scale images and medical images. The algorithm is implemented using MATLAB version 7.0. The results are shown here for the tested 256 x256 gray-scale images, shown in Fig. 7..

B. Performance Metrics

We evaluate mainly the performance according to the following metrics.

Measure of imperceptibility

PSNR (Peaked Signal to Noise Ratio) is the measure for calculating the difference between the original image and the stego-image. The PSNR for an image of size N x N is given as follows:

$$PSNR = 10 \log10 (2552/ MSE), (dB)$$

$$MSE = (1/N*N) \sum\sum (xij - x'ij)^2 ,$$

The MSE is the Mean Square Error, xij stands for the image pixel value in the cover image and x'ij is for the pixel value at position (i, j) in the image after inserting secret message.
When values of MSE are below 0 dB, the noise power is larger than the signal. For identical images, the PSNR is infinite. A high value of PSNR means better image quality (less distortion).
Generally it is observed that when the PSNR is 40 dB or larger, then the 2-images are virtually indistinguishable by human observer.

Measure of structural similarity

The structural similarity (SSIM) is composed of three values: Luminance comparison; Contrast comparison; and Structural comparison. These components are normalized such that they are 1.0 for identical images. The SSIM index is the product of these three components (raised by an exponent, if required).
The formula for this measure is given by

$$SSIM (E, F) = \frac{(\mu x \mu y + C1) (2 \sigma xy + C2)}{(\mu x2 + \mu y2 + C1) (\sigma x2 + \sigma y2 + C2)}$$

where μx , μy , σx, σy , and σxy local statistics parameters of the two images E and F and C1 , C2 are constants used to avoid division by zero.

Kullback-Leibler Divergence (KLDiv)

K. L. divergence is a measure of distance between two probability distributions. Let random variable C and S denote the cover image and stego image respectively, and let PC and PS represent the probability mass functions (pmfs) of C and S, respectively. The K-L divergence between these two pmfs, PC and PS, is defined as:

$$D (PC\|PS) = \sum g \in G [PC (g) \log (PC (g)/PS (g)]$$

where $g \in G \approx \{ 0, 1, 2, ..., 255\}$ is the pixel value in gray scale images.

Images	**CDF9/7**	**SLT**	**CTT**	**DDDT DWT**	**DD DWT**
c3.jpg	27.747	37.131	40.560	46.011	51.888
Tulips.jpg	24.823	38.597	41.874	42.826	48.543
Tooth1.jpg	33.830	45.228	43.708	53.093	58.645
New7.tif	25.994	35.105	38.846	45.112	50.479
New8.tif	21.746	31.303	33.778	43.882	49.956
New11.tif	24.131	32.302	35.501	44.036	49.137
New12.tif	26.775	36.122	37.028	49.744	55.419
C2.bmp	30.791	38.155	40.881	51.960	57.927
Baboo.bmp	21.856	31.280	32.762	44.025	50.006
C1.png	31.546	38.871	41.906	51.444	57.459
Peppers.jpg	30.192	37.834	41.327	49.286	56.493
Zoneplate .png	8.671	23.574	28.037	35.999	39.945

VI. RESULTS

The proposed algorithm is analysed using the performance metrics, PSNR, SSIM and KLDiv.

A. Imperceptibility

In Table 1, we summarize the results of PSNR for different transforms obtained on implementing the proposed algorithm using different format test images with the payload of 2000 bytes. The results of the PSNR are also depicted in Fig. 4.

From Fig. 4, it can be observed that CTT-based method is providing better stego-image quality than CDF9/7 and SLT irrespective of the image format. However, it is observed that CTT-based method is performing better for .jpg image than .png image format in terms of imperceptibility. Overall, DD DWT is showing best results amongst all transforms.

B. Structural Similarity

The comparison based on SSIM for the different transforms is presented in Fig.5 for different image formats. It may be noted that CTT and DD DT DWT both show perfect structural similarity between the original image and stego image for all image formats (SSIM ≈ 1). It can also be observed that CTT based algorithm is better option than the SLT for images of formats .tif, .bmp and .png whereas SLT is better option for .jpg images.

C. Probable security

The results of KLDiv for different transforms used in the proposed reversible algorithm are shown in Fig.6. It is observed that CTT and DD DT DWT show almost perfect probable security as KLDiv ≈ 0 irrespective of the image format whereas CDF 9/7 based algorithm is not found to be appropriate for .tif images.

Table 1. PSNR of proposed P-RDH algorithm based on different transforms
(embedding threshold value=35; Normalizing hard threshold value=0.9; embedding capacity=2000 bytes)

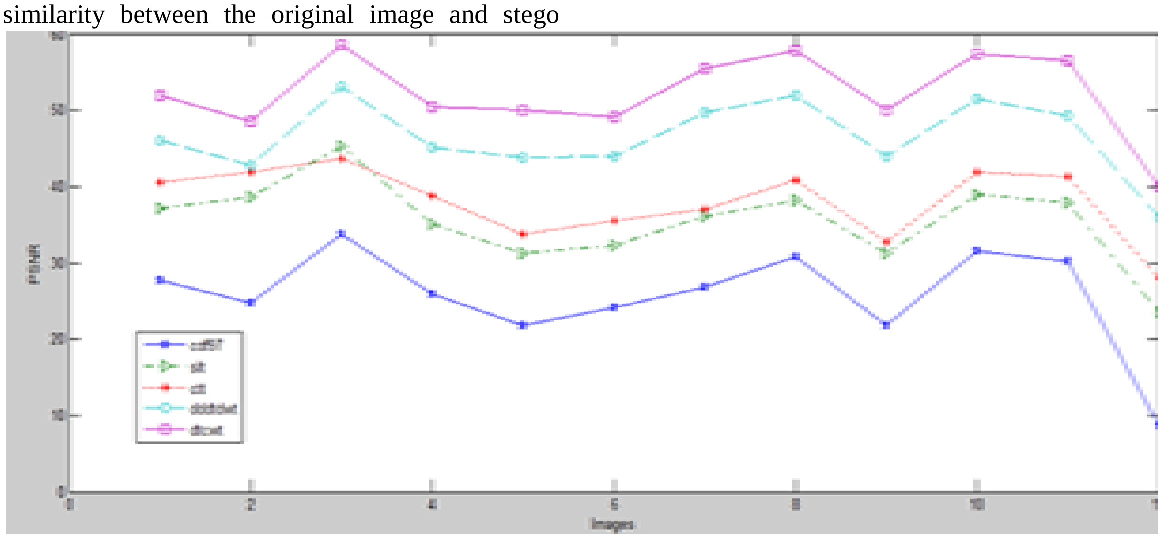

Figure4. PSNR values for the proposed P-RDH based on different transforms for different image formats with threshold value = 35 and normalization hard threshold value= 0.9

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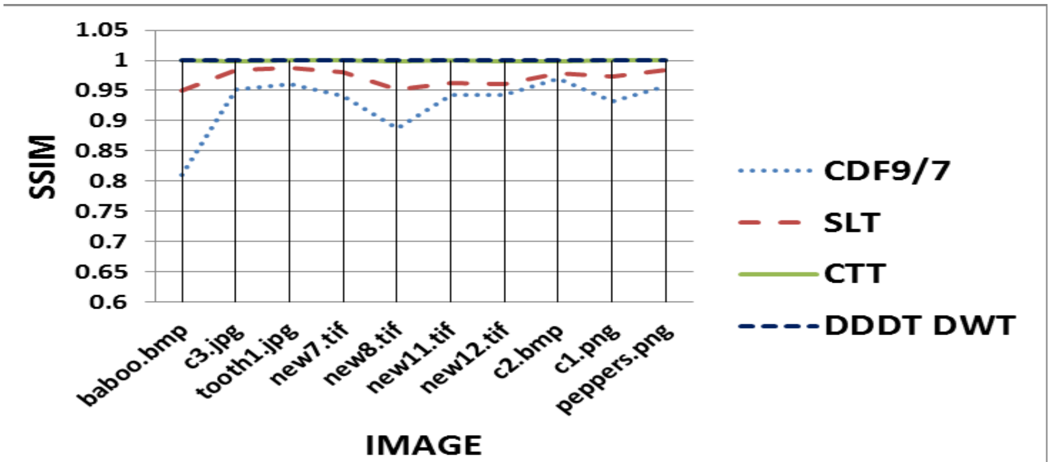


Figure 5. Comparison of SSIM values for proposed P-RDH method based on different transforms. The results are shown for different image formats.

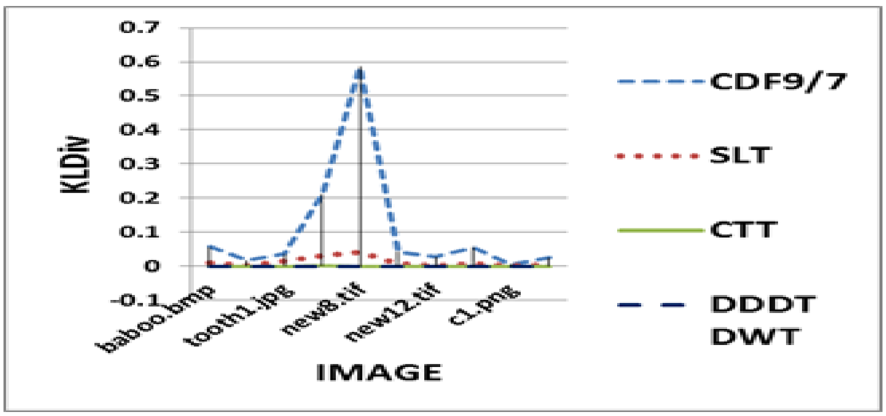


Figure 6. Comparison of KLDiv values for proposed P-RDH method based on different transforms. The results are shown for different image formats

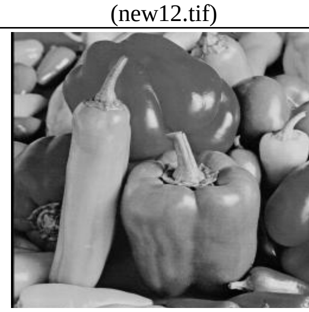

(c3.jpg)


(baboo.bmp)


(new8.tif)


(new12.tif)


(tooth1.jpg)


(new7.tif)

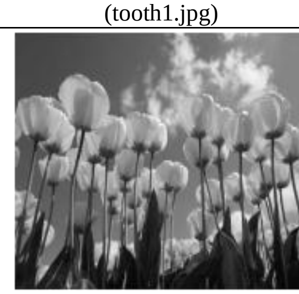

(tulips.jpg)

Figure7. Test Images

VI. Conclusion

A perceptual RDH technique based on CTT is presented and its comparative analysis is done with other transforms such as CDF 9/7, SLT, and DD DT DWT in terms of Imperceptibility, Structural Similarity and Provable Security, respectively. The secret message after encoding by T-codes is embedded in the high sub-bands obtained of the cover image using these transforms. The reversible embedding technique used is known as a Companding technique. Through the experimental results it is found that the CTT and DD DT DWT based proposed method show better results than other transforms such as CDF9/7 and SLT in terms of Imperceptibility, Structural Similarity and Probable Security. These transforms not only provide robustness but provide better embedding capacity. It may be noted tht the use of T-codes at pre-processing stage not only adds another security layer but also helps the receiver at decoding stage to retrieve the correct message from stego-image. The original image is recovered almost 100% from the stego-image.

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