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A Reversible Image Steganographic Algorithm Based on Slantlet Transform

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Abstract - In this paper we present a reversible image steganography technique based on Slantlet transform (SLT) and using advanced encryption standard (AES) method. The proposed method first encodes the message using two source codes, viz., Huffman codes and a self-synchronizing variable length code known as, T-code. Next, the encoded binary string is encrypted using an improved AES method. The encrypted data so obtained is embedded in the middle and high frequency sub-bands, obtained by applying 2-level of SLT to the cover-image, using thresholding method. The proposed algorithm is compared with the existing techniques based on wavelet transform. The Experimental results show that the proposed algorithm can extract hidden message and recover the original cover image with low distortion. The proposed algorithm offers acceptable imperceptibility, security (two-layer security) and provides robustness against Gaussian and Salt-n-Pepper noise attack.

Index Terms - Reversible Steganography, DWT, SLT, Thresholding scheme, PSNR, AES, Huffman codes, T-codes

1. INTRODUCTION

Data hiding or steganography is the art and science of hiding information into a carrier media (such as text, image, audio or video etc.) so that it conceal the existence of a hidden information and its detection becomes difficult. There are applications in which it is desirable to recover the original cover from the stego-image without any distortion after hidden data extraction. There are many papers on reversible steganography in literature [12, 15, 20-24]. The summary of such algorithms may be seen in the papers [2], [3].

The three basic requirements of steganography algorithm are Imperceptibilty, high embedding payload and security [9, 10, 16]. The organizations such as banking, commerce, diplomacy and medicine, private communications are essential. Security is an important issue in the information technology now-a-days. Modern cryptography provides a variety of mathematical tools for protecting privacy and security that extend far beyond the ancient art of encrypting messages. However, for carrying out confidential communication over public networks, simply concealing the contents of a message using cryptography is found to be inadequate as it can still raise suspicion to eavesdroppers. People have found the solution to this problem in Steganography. The image steganography techniques may be classified into two categories: Reversible techniques in which receiver wish to retain the original message after extracting the hidden message from the stego-image and Irreversible techniques in which the objective of receiver is only in extracting the hidden message from the stego-image. In medical profession and law enforcement fields, it is not only the hiding and recovery of message required perfectly but also the recovery of original image is important for the examination. The authors have used synonyms to Reversible technique as distortionless or lossless technique. Xuan et al. [20-23] have presented distortionless data hiding based integer wavelet transform. Celik et al. [3] have proposed a reversible data hiding method based on the idea of first compressing portion of the signal that are susceptible to embedding distortion and then transmitting it as part of embedded payload. Sushil Kumar and S.K. Muttoo[12] have proposed a distotionless steganographic algorithm based on slantlet transform and shown that it outperforms than the DWT in terms of PSNR. Panda and Meher [13] have shown that Slantlet Transform (SLT) offers superior compression performance compared to the conventional DCT and the DWT based approaches. Ni et al. [12] presented a reversible data hiding algorithm based on histogram shifting with a quite limited embedding payload Tian [17] proposed a high capacity reversible data hiding scheme by using a difference expansion. Xian-ting Zeng et al. [24] have proposed a lossless data hiding scheme by using dynamic reference pixel and multi-layer embedding. This scheme can offer very high embedding capacity and low image degradation.

In this paper, we propose a reversible image steganographic method based on CTT. The proposed scheme can offer high imperceptibily than the existing scheme based on DWT and low image degradation. The use of T-code is a plus point as it provides self-synchronization at decoding stage and a layer of security as receiver will need decoding key (generated at the time encoding) for extracting the original message at decoding stage. There is another layer of security added at embedding scheme by hiding the secret bit randomly, i.e., using random permutation of sub-bands coefficients. Advanced encryption standard (AES) used in the scheme is one of the most powerful techniques of cryptography which can be used as an integral part of steganographic system for better confidentiality and security. Dilbagh singh et al. [4] has proposed private key encryption technique that can be used for data security in modern cryptosystem. Their technique uses the concept of arithmetic coding and can also be clubbed with any of the encryption system that works on floating point numbers.

The rest of the paper is organized as follows: Section 2 presents a review of Slantlet Transform. We introduce briefly the thresholding algorithm applied for embedding in our

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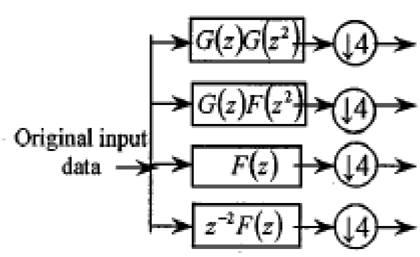
method in Section3. Section 4 presents the proposed algorithms. The experimental results and their analysis is presented in Section 5. Conclusions and future scope are presented in Section 6.

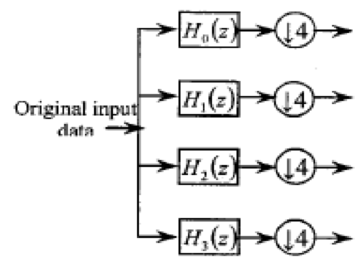
2. SLANTLET TRANSFORM

In image compression, the Wavelet transforms produces much less blocking artifacts than the DCT. They are adopted in JPEG2000. They also perform well in image de-noising. However, 2D wavelet transform is, intrinsically, a tensor-product implementation of the 1D wavelet transform, and it provides local frequency representation of image regions over a range of spatial scales, and it does not represent 2D singularities effectively. Therefore it does not work well in retaining the directional edges in the image, and it is not sufficient in representing the contours not horizontally or vertically.An orthogonal discrete wavelet transform with approxim ation order two, i.e., with two zero moments and improved time localization, known as Slantlet transform (ST), was introduced by Ivan W. Selesnick[14] in 1999. It uses a special case of a class of bases described by B. Alpert et al. [1], the construction of which relies on Gram-Schmidt orthogonalization. It is based on a filterbank structure, implementing in a parallel form, employing different filters for each scale. In DWT, some of these parallel branches employ product of basic filters, shown in figure 1. The Slantlet filter branches, however, do not employ any product form of implementation, as shown in figure 2 and hence ST possesses extra degrees of freedom. Ivan W. Selesnick [14] has shown that due to this property, ST can be implemented employing filters of shorter supports, and yet maintaining the desirable characteristics like orhtogonality and an octave-band characteristics, with two zero moments. For k=2, the iterated filters of Daubechies are of length 10 and 4 whereas in case of SLT they are of length 8 and 4, i.e., 2-scale SLT filterbank has a filter length which is two samples less than that of a 2-scale iterated D_2-filterbank. This difference grows with the number of stages. Though SLT has no tree structure like DWT, it can be efficiently implemented with same order of complexities as of DWT.

Data compression using 2-scale SLT filterbank involves three steps: transformation of input signal using the SLT, thresholding of transformed coefficients and reconstruction of the signal from the thresholded coefficients. G. Panda et al [13] have shown that SLT provides improves time localization than the DCT and DWT.



(a)

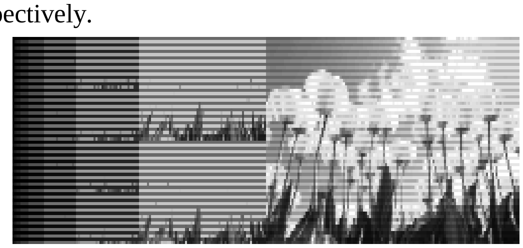


(b)

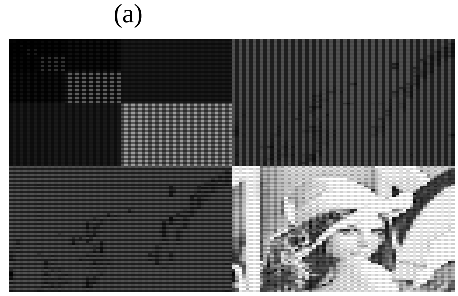
Figure 1: (a) Two-scale iterated filterbank using the DWT (b) Two-scale filterbank structure using the SLT.

Also considering various compression parameters such the percentage of energy retained and the MSE of different PQ signals, it is observed by them that the accuracy of the reconstruction of SLT method is better than that the DCT and DWT, i.e., the SLT based compression technique yields better performance compared to both the DCT and DWT. In the compression scheme using SLT, the data is first applied to two-level filter structures $H_0(z)$, $H_1(z)$, $H_2(z)$, and $H_3(z)$. The output of these filters are down sampled by a factor of 4, which are the transform coefficients of the input data obtained after the convolution operation of the original data with the filter coefficients , as shown in figure 1. The transform coefficients are then thresholded using a suitable parameter. The inverse slantlet transform are performed on these thresholded coefficients to reconstruct the original data.

The figure 2(a) is the 1-level decomposition obtained after applying 1-d slantlet filters to image 'Tulips.jpg' and decomposing into low (L) and high sub-bands(H). The figure 2(b) shows the 2-level decomposition of image lena. bmp when the 1-D slantlet filters are used first on the rows of image and then on the columns, resulting into sub-bands HH, HL, LH and LL respectively.



(a)



(b)

Figure 2. a) 1-level Slantlet image of "Tulips.jpg", and b) 2-level Slantlet image of 'lena.bmp'

Nagaraj B Patil et al [11] have shown that as threshold level increased better compression ratio and PSNR can be achieved for the test data. It has been observed that most of the middle and high frequency coefficients in the HL, LH or, HH subbands obtained from SLT are of low magnitudes. As these bands constitute 75% of all SLT coefficients, the highest payload can be 0.75 bit per pixel (bpp). Table 1 lists the payload of four different images (256x256) under different thresholds “alternately” (unless you really mean something that alternates). For ‘Flower.jpg’, if threshold T is set to be 8, the payload is 0.645 bpp. It shows that over 86% coefficients in the high frequency subbands are used for data hiding in the Threshold embedding technique.

Image	T=4	T=6	T=8
Lena	0.547	0.58	0.603
Tulips	0.504	0.538	0.566
Flower	0.589	0.623	0.645
Bunkbed	0.50	0.54	0.57

Table 1: Threshold vs payload

3. THRESHOLDING METHOD

Threshold embedding method for the lossless data hiding is given by Xuan et al. [21]. We predefine a threshold value. 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, 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:

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

The Figure provides an example to hide the message, s=101010 into a block of 3x3 where T=10.

3	**-7**	**11**
12	**0**	**-1**
8	**-15**	**5**

Embedding T=10; s=101010

Extraction

6	**-13**	**21**
18	**0**	**-1**
16	**-24**	**11**

4. PROPOSED ALGORITHM

The proposed reversibhle image steganography algorithm embeds data into the first level high frequency subbands of the cover image. Preprocessing is performed prior to data embedding to ensure that no overflow/underflow takes place. The stego-image carrying hidden message is obtained after taking the inverse contourlet transform. Fig. 3 is the flowchart of the proposed embedding data hiding ande Figure 4 is the flowchart for hidden data extraction and original cover image recovery.

The embedding algorithm is summarized as follows:

Algo: 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.

Step 2. Modified AES encryption algorithm [25] is applied on the compressed data.

Step3. Apply pre-processing to prevent possible “overflow” during embedding (e.g., replacing the grayscale values 0 to 255 into 15 to 240).

Step4. Consider 8-bit greyscale image and decompose it into 4 sub-bands : one lowpass sub-band and 3 sub-bands for horizontal and vertical directions by applying 2-level SLT, viz., HL,LH and HH

Step5. Embed data in the high horizontal and vertical sub-bands of SLT using thresholding method (taking threshold value=35).

Step6. Obtain the stego-image by taking the inverse SLT of the modified image of step5.

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Algo: Extraction

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Step 1. Apply CTT to the stego image

Step 2. Extract secret data from the four horizontal and vertical subands of CTT inverse thresholding technique.

Step 3. Improved AES decryption algorithm[21] is applied on the extracted codes to obtain the actual encoded T-codes.

Step 4. Obtain the original message by T-decoding the secret data, with the help of encoding key

Step 5: Recover the original image by removing the hidden message from the stego-image

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IMAGE	WLT +HUFF +AES	WLT +HUFF +AES (adding Gaussian)	SLT +HUFF +AES	SLT +HUFF +AES (adding Gaussian)
I1	19.922627	19.922627	23.235624	21.450025
I2	18.188314	18.188314	34.095894	32.143663
I3	17.292913	17.292913	26.616492	24.477793
I4	17.454110	17.454110	25.362884	23.197050

Table 2: PSNR values based on Wavelet and SLT using Huffman encoding (secret message = 5000 bits)

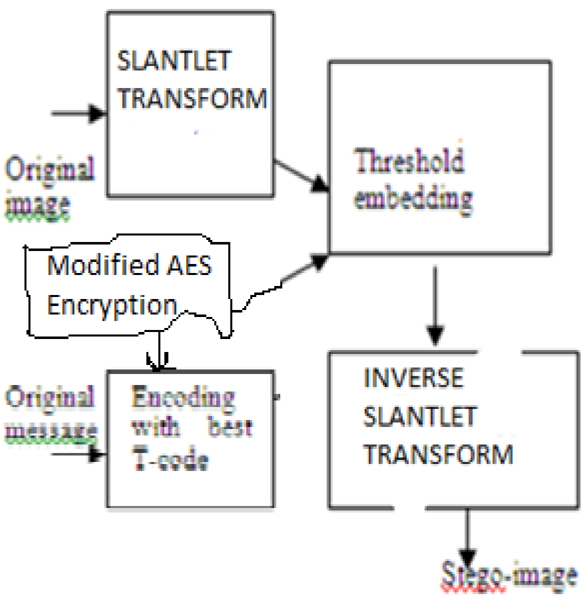

Figure 3: Block diagram of Embedding method

5. EXPERIMENTAL RESULTS AND ANALYSIS

To evaluate the performance of the proposed data hiding algorithm, we have used 128 x128 and 256 x256 gray scale images. Simulations are done using MATLAB 8.0. We have compared the performance of the proposed steganographic method based on SLT using T-codes as endcoder, improved AES as encryption and reversible thresholding technique as embedding with the corresponding steganograpic method based on Wavelet. We have tested number of images such as standard images and medical images. We have used the metric PSNR for measuring the stego-image quality.

Imperceptibility

The perceptibility measure for the quality of image used is PSNR given by

$$PSNR = 10 \log_{10} (255^2 / MSE)$$

$$MSE=(1/N)^2 \sum\sum (x_{ij} - x'_{ij})^2$$

where x denotes the original pixel value

Table 2 shows the test results for these methods using only Huffman codes as encoder, Table 3 shows test results using only T-codes as encoder, Table 4 shows the results using Huffman codes and improved AES encryption, and Table 5 shows the results using T-codes and modified AES encryption.

We have shown the results for the four images: I1:Cameraman.tif, I2: Lena.jpg, I3: Nature.jpg, and I4: Scenery.jpg (see Figure 9).

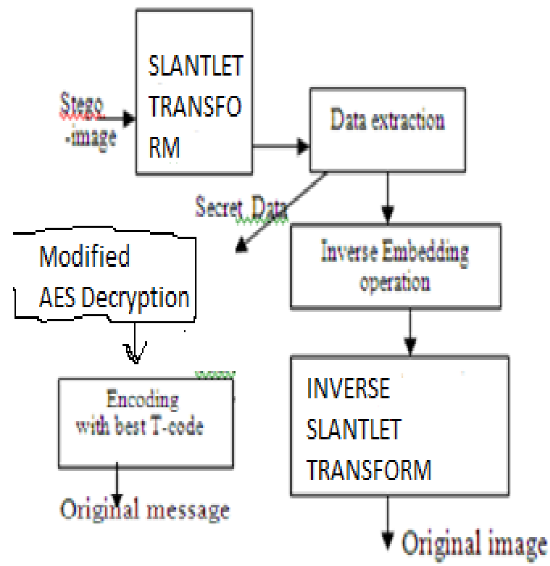

Figure 4: Block diagram of Extraction method

IMAGE	WLT+HUFF	WLT+HUFF (adding Gaussian)	SLT+HUFF	SLT+HUFF (adding Gaussian)
I1	19.921678	19.921678	21.452172	21.452389
I2	18.203956	18.203956	32.140011	32.137198
I3	17.292666	17.292666	24.489907	24.489990
I4	17.453638	17.453638	23.198266	23.200940

Table 3: PSNR values based on Wavelet and SLT using T-code encoding (secret message = 5000 bits)

IMAGE	WLT + TCODE	WLT + TCODE (adding Gaussian)	SLT+ TCODE	SLT+ TCODE (adding Gaussian)
I1	19.276835	18.739734	21.144950	21.146281
I2	16.892371	16.798323	31.866441	31.871396
I3	15.368473	18.578029	24.3046	24.296260
I4	14.086282	9.738723	22.955329	22.951326

Table 4: PSNR values based on Wavelet and SLT using Huffman encoding and AES encr*yption* (secret message = 5000 bits)

Robustness
The figures 5 to 8, we show the bar diagrams for comparison of PSNR values for four images using the proposed algorithm based on slantlet transform, T-codes andf AES method with or without the additon of Gaussian noise (0.01) and compared with the corresponding algorithm for wavelet transform.

Analysis
The results of the PSNR of the proposed method based on SLT is compared with the Wavelet transform and Slantlet transform and are summarized in the table 2 to table 5.
The imperceptibility is found to be better in the SLT based reversible thresholding algorithm than DWT based reversible thresholding method.

IMAGE	WLT+TCODE +AES	WLT +TCODE +AES (adding Gaussian)	SLT+TCODE +AES	SLT+TCODE +AES (adding Gaussian)
I1	18.739734	19.276835	21.143900	21.1446
I2	16.798323	16.892371	31.859676	31.8704
I3	18.578029	15.368473	24.295226	24.2963
I4	9.738723	14.086282	22.952757	22.9471

Table 5: PSNR values based on Wavelet and SLT using T-codes encoding and AES encry*ption* (secret message = 5000 bits)

The algorithm does not need original image for recovering the secret data (It is a blind data hiding scheme). The use of T-codes provides self-synchronization in the decoding stage.
From the above tables it can be seen that SLT along with Huffman compression technique and AES encryption method has slightly better PSNR values than SLT along with T-codes and AES method.
Further, SLT based steganographic method is robust to Gaussian effect (same results have been observed for salt and pepper).

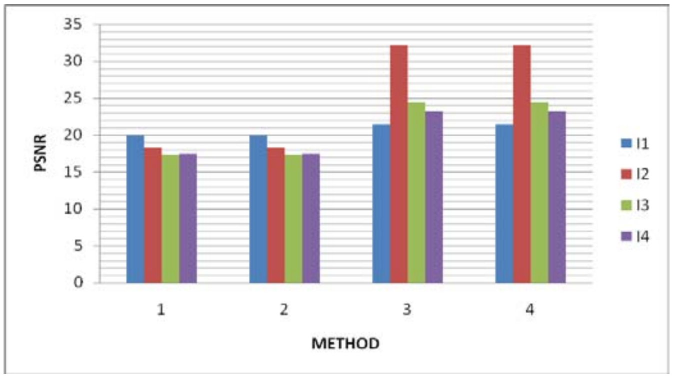

Figure 5: (1) WLT+Huff, (2) WLT+Huff+Gaussian (0.01), (3) SLT+Huff , (4) SLT+Huff+Gaussian

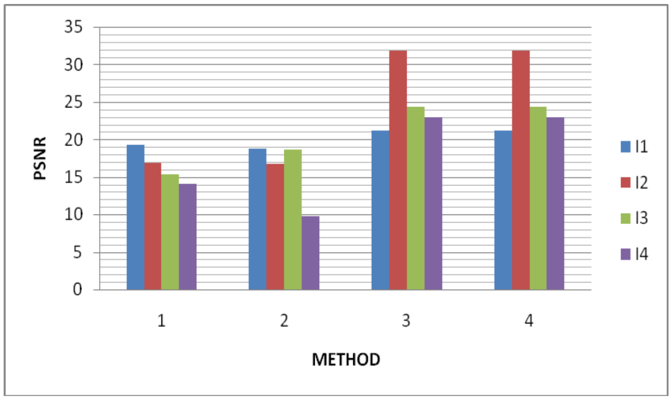

Figure 6: (1) WLT+Tcode, (2) WLT+ Tcode +Gaussian (0.01), (3) SLT+Tcode , (4) SLT+Tcode +Gaussian

6. CONCLUSION AND FUTURE SCOPE

In this paper we have presented
1. a new variable length codes, viz., T-codes for the compression of embedding message.
2. An improved AES for the encryption of the encoded message
3. SLT in place of DWT as they provide better perceptibility and compression.
4. The reversible thresholding technique so that one can recover the original image from the stego-image.

Slantlet transform, which is also a wavelet-like transform and a better candidate for signal compression compared to the DWT based scheme and which can provide better time localization,
Huffman codes have been preferred for data compression by researchers. However, people have been searching for self synchronizing variable length codes since 1970. One of the best self-synchcronization variable length codes which can replace Huffman code is T-code [18-19].We have applied these codes for data compression in the proposed algorithm.
The T-codes are self-synchronizing codes shown to be better than Huffman codes in the decoding process. They also provide a layer of security in the system as one needs encoding key to encode the secret message obtained from the extraction process.
The use of encryption in steganography can lead to 'security in depth'. To protect the confidential data from unauthorized access, an advanced encryption standard (AES) has been suggested by the researchers [5]. AES algorithm is a very secure technique for cryptography and the techniques which use frequency domain are considered highly secured for system for the combination of steganography.
The reversible threshold embedding technique is used for embedding the secret message in the sub-bands of transform image obtained from the cover object by applying 2-level of SLT and results are compared with the data hiding techniques based on wavelet (biorthogonal cdf9/7) transform.

Security

The integration of Compression technique (T-codes) and cryptography technique (Modified AES) with Steganography use three keys – encoding key, encrypted key and threshold value, making the present algorithm a highly secured method.

Robustness

The proposed method provides not only acceptable image quality but also has almost no distortion in the stego-image after adding Gaussian noise or Salt and Pepper noise. The use of SLT has shown better results than DWT in terms of image metric 'PSNR' and robustness.

Recovery

There is no artifact obtained in the stego-image and the original image is recovered with low image degradation from the stego-image.

Embedding Payload

The embedded payload in the proposed embedding technique is same as in case of the DWT techniques.

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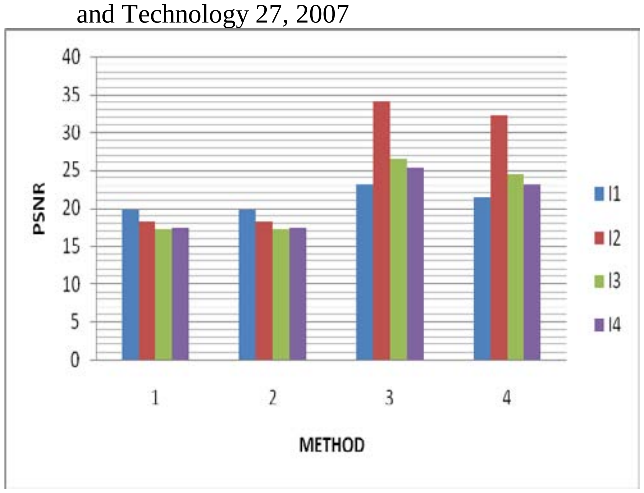

Figure 7: (1) WLT+AES+Huff, (2) WLT+AES+ Huff+Gaussian (0.01), (3) SLT+AES+Huff , (4) SLT+AES+Huff+Gaussian

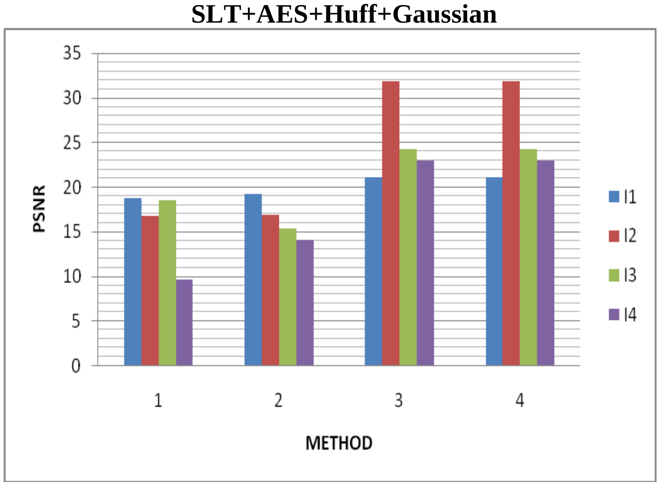

Figure 8: (1) WLT+AES+Tcode, (2) WLT+AES+ Tcode +Gaussian (0.01), (3) SLT+AES+ Tcode , (4) SLT+AES+ Tcode +Gaussian

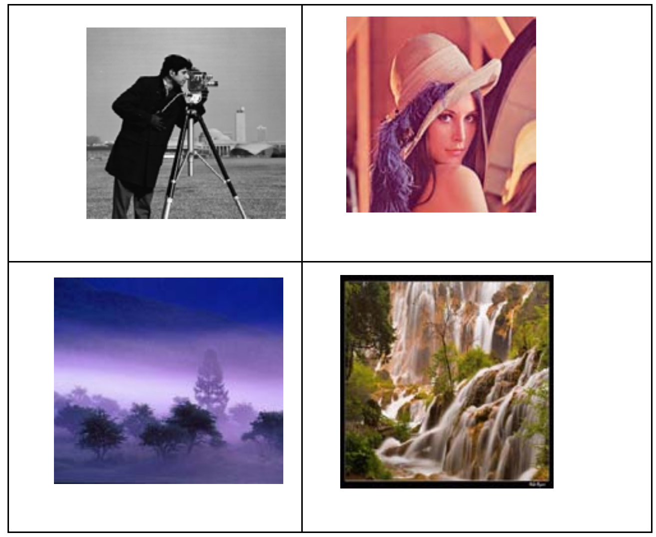

Figure 9: Cover images I1, I2, I3 and I4