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Enhanced Adaptive Data hiding in DWT

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Abstract: *security of the data on internet can be obtained by the steganography. It is combination of science and art for hiding the data or information in cover medium. So, that observer cannot arouse suspicious. In this regards Discrete Wavelet Transform (DWT) plus adaptive quantization are the effective tools for enhancing the cover media visual quality and hence attracts much attention in recent years. In this paper the steganography technique which embeds the secret messages in frequency domain after DWT and adaptive quantization. To improve steganography parameters such as embedding capacity and visual quality of cover media. Here, embedding capacity changes over techniques and quality can be measured with Peak Signal Noise Ratio (PSNR) and Human Visual System (HVS).*
Keywords: *Steganography,Watermarking, DWT, HVS, PSNR, Adaptive Quantization*

I. Introduction

In a highly digitalized world we live today, computers help transforming analog data into digital forms before storing and/or processing. In the meanwhile, the internet develops very fast and hence becomes an important. Major advantage and disadvantage of internet is its transparency. While we (authorized) see the information on the internet and some (unauthorized) users also can see, alter, steal, temper and create loss to information owner. To rectify this situation various procedures are evolved to secure. Those are watermarking and steganography. Watermarking protects the author's property right of digital data by some concealed watermarks. On the other hand steganography envelopes the original data into cover medium [13,17]. According to the location where watermarks or confidential data are embedded, both categories can be further classified as the spatial domain methods and the frequency domain methods [12]. The spatial domain is the regular image space. In which position change in spatial domain is directly projects to HVS [11, 18]. A transition function transforms the regular image space into to frequency domain. In which position change in frequency domain cannot directly visualized by human [12, 18].

One of the important methods of steganography is to replacement the original bits with secret data bits. Because of their simple implementation and excellent concealment to HVS characteristics [1], usage of HVS characteristics widespread in developing steganography algorithms. For steganography, several steganalysis procedures have been proposed with Least Significant Bit (LSB) replacement. Such steganography methods have been designed i.e., are regular and singular groups' method [2], sample pair analysis method [3], weighted stego-image method [4] and non-zero DCT coefficient embedding method with quantization [5]. Similarly, for MLSB replacement steganography, several steganalysis procedures have been proposed that are LSB substitution method for varying and fixed mood embedding [6]. Apart from that embedding secret message in different bands such as horizontal coefficients CH, vertical coefficients CV and diagonal coefficient CD [14]. All methods are prone to steganalysis from Pixel Group Trace Model-Based Quantitative Steganalysis for MLSB Steganography [7] and also quantitative analysis has designed by using embedding coefficients [8].

Further improvement of superior cover medium quality, uniform quantization quantizes the DWT coefficients with fixed intervals [9] and adaptive quantization quantizes the DWT coefficient according to their characteristics [10, 14] has been proposed. In this paper we are proposing a new method that optimizes the capacity and quality requirement of the image. It reads spatial domain image coefficient and convert into frequency domain by using DWT transformation. Then by taking DWT coefficients apply Adaptive Quantization technique and displacement technique, to convert quantized coefficients. In this quantized coefficients, Non-zero quantized coefficients data can be embedded. In this technique like all others technique PSNR value is using for quality matrix [1, 2, 5, 6, 8, 15].

Organization of this remaining paper as follows. Section 2 reviews the background related knowledge with some numerical example of DWT and discusses the detail work of adaptive quantization and uniform quantization with numerical example. In section 3, illustrate the non-zero embedding technique. Experimental results, analysis and future scope are demonstrating the section 4. In last section, it summarizes the entire work, results and some concluding remarks are provided.

II. Background

A. Discrete Wavelet Transform

In comparison to other transforms, DWT transforms proved to be the best for image transformation [19]. DWT transform the image coefficients from special domain to frequency domain in this paper we exploring Haar-DWT. Input signal is decomposed by using basic operations into a set of functions that are called wavelets. Wavelets like symlet, Haar, Coiflet and Daubechies are one family of wavelets Discrete Wavelets. In this type of wavelets, different levels of decompositions are exists i.e.., are 1D, 2D,……..,n D (Dimensional). Original signal of M x N is decomposed in 1D-Haar-DWT by make use of horizontal and vertical addition and subtraction operation functions of level 1 /1D DWT. Fig. 1 & 2 illustrate in detail. After the decomposition image is divided in to four sub-band image coefficient such HH, HL, LH and LL and reconstruction of original image from DWT coefficient.

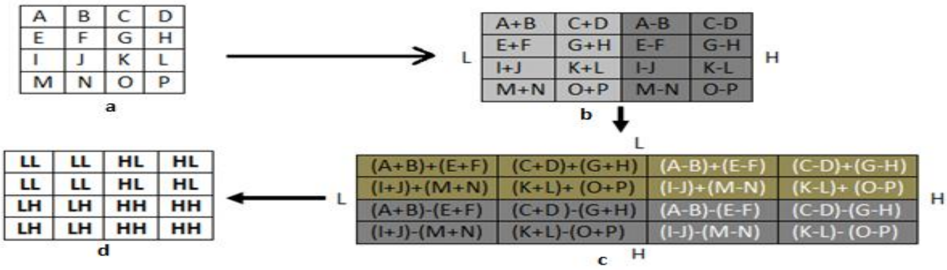


Figure 1 DWT transformation a). Original Coefficients b). After Horizontal Transformation c). After Vertical Transformations d). LL, HL, LH and HH sub-bands

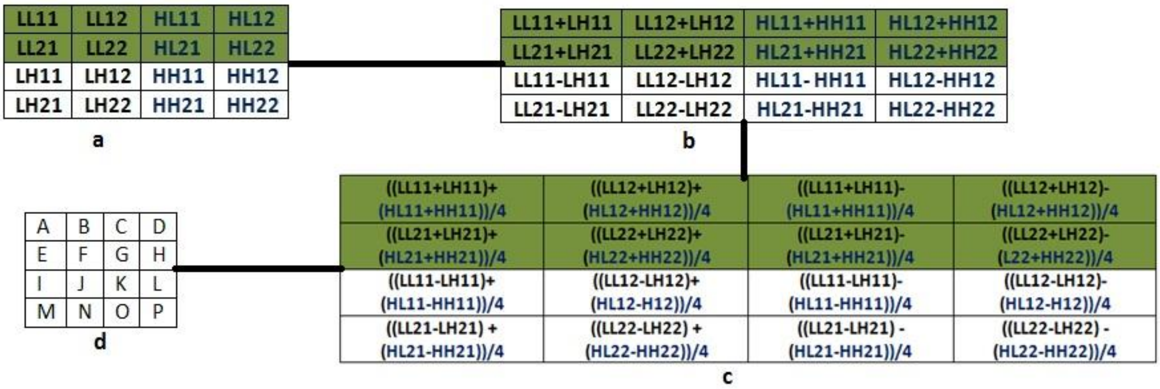


Figure 2 Inverse DWT transformation a). LL, HL, LH and HH sub-bands Coefficients b). After Horizontal Transformation c). After Vertical Transformations d). Original Coefficients

LL band coefficients reflect the original image. Changes in this sub-band cause addition maximum noise in original image as show in fig. 3. HL, LH and HH sub-bands coefficients reflect the approximation and edges information only, so changes in this sub-band cause addition of minimum noise in original image. From that insertion of secrete image will maximum done at HL, LH and HH bands only.

Figure 3 Single-Level DWT of Lena

B. Quantization

Quantization improves not only compression ratio, but also guarantees the minimum noise addition. They are two types of Quantization techniques exist that are a) Uniform quantization and b) Adaptive Quantization.

Uniform Quantization: It divides DWT coefficients in to fix number of quantization intervals. Assume I is an M x N gray image, its pixels can be described as follows

$$I = \{x_{ij} | 1 \le i \le m, 1 \le j \le n, x_{ij} \in \{0,1,2\ldots.255\}\}$$

By performing DWT on I, we obtain four sub-bands HH, HL, LH and LL of each size M/2 x N/2 . Apply the uniform quantization on the obtained DWT coefficients of all sub-bands. Most images, calculate the average of the maximum and the minimum that is mean 'ω' then it can subtract from the distribution coefficients and divide with standard interval width and place sign. Mean 'ω' is formulated as follows

$$\omega = \left\{ \frac{\max + \min}{2} \right., \max = \max(x_{ij}), \min = \min(x_{ij}), x_{ij} \in \{0,1,2\ldots.255\}$$

The uniform quantization encoding process is formulated as following equation

$$Q(i,j) = sign(H(i,j)) \left[\frac{|H(i,j) - \omega|}{\Delta b} \right]$$

Where Q(i, j) is the quantization result at position (i, j), H(i, j) is represent the original DWT coefficient at position (i, j), Δb stands for interval width for quantization, and ω is mean. Below fig. 3 demonstrate the simple numeric example for this uniform quantization process.

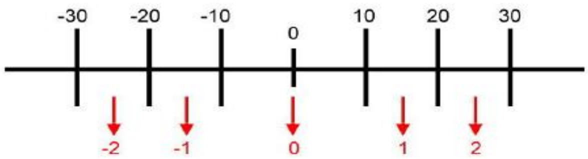


Figure. 4 Simple Example for uniform quantization

After the encoding process, the uniform de-quantization is formulated in equation below

$$R_{Q(i,j)} = \begin{cases} (Q(i,j) + r)\Delta b + \omega, Q(i,j) > 0 \\ (Q(i,j) + r)\Delta b + \omega, Q(i,j) > 0 \\ 0, \quad otherwise \end{cases}$$

Where $R_{Q(i,j)}$ is reconstructed coefficients at (i, j) position and r is optional parameter.

Adaptive Quantization: It divides DWT coefficients into variable quantization interval depending on the asymmetric characteristics of image. The adaptive quantization on the resulting DWT coefficients sub-bands. For most images, each sub-band and DWT coefficient subtracting median α of DWT coefficient respective band, construct the displacement matrix D.

$$\alpha = \begin{cases} \text{If } \frac{n}{2} \neq 0, \text{then} \{x_i | 1 \le i \le n, i = \frac{n}{2} + 1 x_1 \le x_2 \le \ldots \le x_n\} \\ \text{If } \frac{n}{2} = 0, \text{then} \{\frac{x_i + x_{i+1}}{2} | 1 \le i \le n, i = \frac{n}{2} x_1 \le x_2 \le \ldots \le x_n\} \end{cases}$$

Where n are the number of coefficients and x_i is the i^{th} coefficient.

$$D(i,j) = H(i,j) - \alpha$$

Where D(i, j) is displacement matrix coefficient at position (i, j) and H(i, j) is DWT coefficient at position (i, j).

$$\Delta b_L = \left\{ \frac{|\alpha - \min|}{l/2} \right., \min = \min(H(i,j)), H(i,j) \in \{0,1,2\ldots.255\}$$

$$\Delta b_R = \left\{ \frac{|\max - \alpha|}{l/2} \right., \max = \max(H(i,j)), H(i,j) \in \{0,1,2\ldots.255\}$$

To perform adaptive quantization, the right interval width Δb_R, left interval width Δb_L and median 'α' for each sub-band displacement matrix have to compute in advance.

The adaptive quantization encoding process is formulated by the following equation

$$Q(i,j) = sign\left(D(i,j)\right)\left\lceil \frac{\left|H(i,j)-\alpha\right|}{\Delta b_L} \right\rceil$$

$$Q(i,j) = sign\left(D(i,j)\right)\left\lceil \frac{\left|H(i,j)-\alpha\right|}{\Delta b_R} \right\rceil$$

Where D(i, j) is displacement matrix coefficients at position (i, j) and Δb_L and Δb_R is right and left interval widths. Below fig. 4 demonstrate the simple example for this adaptive quantization process.

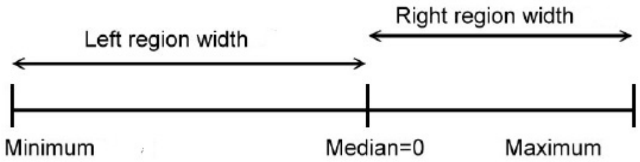


Figure. 5 simple adaptive quantization structure

The adaptive de-quantization process is formulated in below equation

$$R_{Q(i,j)} = \begin{cases} \left(Q(i,j)+r\right)\Delta b_R + \alpha, Q(i,j) > 0 \\ \left(Q(i,j)-r\right)\Delta b_L + \alpha, Q(i,j) < 0 \\ 0, \qquad otherwise \end{cases}$$

$R_{Q(i, j)}$ is reconstructed values at position (i, j) and r is optional parameter.

III. Data Embedding and Extraction

The frequently used data embedding technique in steganography method is the LSB substitution technique. In a gray-level image, every pixel consists of eight bits. One pixel can hence display 2^8 =256 variations. The weighting configuration of an eight bit number is from right most bits (Most Significant Bit-MSB) to left most bits (LSB) is decreasing. The basic concept of LSB substitution is to embed the confidential data at the rightmost bits (bits with the smallest weighting) so that the embedding procedure does not affect the original pixel value greatly [16]. If k (k > 1) number of LSBs are substituted that substitution called as MLSB.

In this type of fixed secret data embedding is vulnerable to the steganalysis, furthermore the confidential data easily stolen by simply extracting the k-right most bits or LSB. To improve further security level data is not embedded, at all coefficients LSB positions in LSB substitution and in LSB substitution technique data embedded at various bands and variety of ways. That type of technique is illustrated below

A. Embedding into non-zero AC coefficients using DCT

The new category near reversible data embedding is emerging in the area of digital watermarking and steganography for providing security to the multimedia contents. In this technique data embedded at non-zero AC elements of quantized Discrete Cosine Transforms (DCT) coefficients in the middle frequency region of DCT blocks as follows [5]

$$e = \begin{cases} sign(c) * floor\left(2\log_2\left(2|c|\right)\right) & if I_i = 0 \\ sign(c) * floor\left(2\log_2\left(2|c|\right)-1\right) & if I_i = 1 \end{cases}$$

Where c is a non-zero DCT coefficient element, e is the modified version of c and I_i is i^{th} data bit.

B. Extracting from non-zero AC coefficients using DCT

The data extraction is an inverse process of data embedding. Data bits can be extracted using following equation

$$I_i = \begin{cases} 0 & if\ \frac{e}{2} = 0 \\ 1 & otherwise \end{cases}$$

Where e is the modified coefficient during the embedding process and I_i is the i^{th} extracted data bit.

The proposed technique as follows:

C. Non-zero DWT plus adaptive quantization coefficient embedding Algorithm

Lets us assume I original image size of 512 x 512. Apply DWT for original image I then resultant we obtain DWT coefficients in HH, HL, LH and LL sub-bands. Find Median for all sub-bands and represented with ω. Then subtract median of each sub-band with coefficient of the sub-bands resultant we can called as Displacement matrix. Then calculate the Quantization matrix. Embed the secret message S into quantized values using embedding formula. Apply inverse process to obtain STG stego image. Below algorithm illustrate the embedding of secrete data S into original image I.

Embedding Algorithm

----

1. Read the cover image I= {I(I,1), I(1,2),…., I(512,512 }.
2. Find the DWT coefficient for cover image in HH, HL, LH and LL sub-bands.
3. Find the displacement matrix D for all sub-bands.

i) Select a sub-band and identify the median ω

ii) Subtract the ω median with all sub-band coefficients.

4. Select the left and region intervals for all sub-bands
5. Calculate the adaptive quantization matrix for HH, HL and LH sub-bands

```
for i=1:256 increment by one step
      for j=1:256 increment by one step
            if D(i,j)< α
            Q(i, j)=sign(D(i,j)) *floor(D(i,j)- α)/ΔL)
            else
            Q(i, j)=sign(D(i,j)) *floor(D(i,j)- α)/ΔR)
            end
      end
end
```

6. Calculate the embedding matrix for HH, HL and LH sub-bands

```
for i=1:256 increment by one step
      for j=1:256 increment by one step
         if Q(i,j)!=0
            if s(i)== 0
                  e(i,j)=sign*floor (2log2(2|c|))
            else
                  e=sign*floor (2log2(2|c|-1))
            end
         end
      end
end
```

7. Reconstruct the image using reverse process of above and inverse DWT.

D. Non-zero DWT plus adaptive quantization coefficient Extracting Algorithm

Lets us assume STG is stego image size of 512 x 512. Apply DWT for stego image STG then resultant we obtain DWT coefficients in HH, HL, LH and LL sub-bands. Find Median for all sub-bands and represented with ω. Then subtract median of each sub-band with coefficient of the sub-bands resultant we can called as Displacement matrix. Then calculate Quantization matrix. Extract the secret Message S from STG stego image using extraction formula. Apply inverse process to obtain I^I Original image. Below algorithm illustrate the extracting of secrete message S from stego image STG.

Extracting Algorithm

----

1. Read the stego image S= {S(1,1),S(1,2),…., S(512,512) }.
2. Find the DWT coefficient for cover image in HH, HL, LH and LL sub-bands.
3. Calculate the extracting matrix and retrieving secrete data from HH, HL and LH sub-bands

```
for i=1:256 increment by one step
      for j=1:256 increment by one step
         if D(i, j)!=0
            x=abs(A(i,j))
            if if(mod(D(i,j),2)==0)
            s=[s 0];
```

```
                    Ex(i,j)=sign(D(i,j))*pow(2, x/2-1)
                    else
                    s=[s 1];
                    Ex(i,j)=sign(D(i,j))*pow(2, (x+1)/2-1)
                    end
            end
      end
    end
```

4. Reconstruct the image using reverse process of above and inverse DWT.

IV. Results and discussion

We use MATLAB R2009a and various JPEG formatted of 512 x 512 size gray scale images in our experiment.

Example: Considered first 8x8 matrices from **Aerial** image as it shown in figure 5 (a). Apply embedding algorithm. Step 2, it transform the original coefficients to DWT coefficients by applying DWT-Haar transform as shown figure 5 (b). Then step 3,4 and 5, it transform the DWT HH, LH and HL sub-band coefficients to Quantized coefficients by apply adaptive quantization as shown in figure 5 (c). Then step 6, embed secrete data 110011010111001101010111 into Quantized coefficients to get embedded quantized coefficients as shown figure 5 (d). Finally in step 7, reconstruct image by applying inverse DWT to embedded quantized coefficients as shown figure 5 (e).

162	162	162	161	162	157	163	161
162	162	162	161	162	157	163	161
162	162	162	161	162	157	163	161
162	162	162	161	162	157	163	161
162	162	162	161	162	157	163	161
164	164	158	155	161	159	159	160
160	160	163	158	160	162	159	156
159	159	155	157	158	159	156	157

a)

LL				HL			
324	323.00	319	324.00	0	0	0	0
324	323.00	319	324.00	0	0	0	0
326	318.00	319.50	321.50	-2.00	5	-0.50	2.50
319.00	316.500	319.50	314.00	1	4.50	2.50	1
0	0.99	5.00	2.00	0	0	0	0
0	0.99	5.00	2.00	0	0	0	0
0	2.00	3.50	0.50	0	-1.00	1.50	1.49
0	1.50	-1.500	1.00	0	3.50	-0.49	2.00
LH				HH			

b)

LL				HL			
324	323.00	319	324.00	0	0	0	0
324	323.00	319	324.00	0	0	0	0
326	318.00	319.50	321.50	-3	3	-1	3
319.00	316.50	319.50	314.00	0	3	2	0
-1	0	3	1	0	0	0	0
-1	0	3	1	0	0	0	0
-1	1	2	0	0	-3	1	1
-1	0	-3	0	0	3	-1	2
LH				HH			

c)

LL				HL			
324	323.00	319	324.00	0	0	0	0
324	323.00	319	324.00	0	0	0	0
326	318.00	319.50	321.50	-3	3	-2	5
319.00	316.50	319.50	314.00	0	3	2	0
-2	0	3	2	0	0	0	0
-1	0	3	1	0	0	0	0
-2	2	2	0	0	-3	2	1
-1	0	-5	0	0	5	-1	2
LH				HH			

d)

161	163	162	162	161	158	163	161
161	163	162	162	161	158	163	161
162	163	162	162	161	158	163	162
162	163	162	162	161	158	163	162
161	163	160	161	161	157	164	163
164	166	160	155	161	161	158	159
159	160	162	157	158	164	158	156
159	160	154	159	157	161	156	158

e)

Figure 5 a) Input 8 x 8 Cover Coefficients ‘C’ b) DWT Cover Coefficients c) Adaptive Quantized Cover Coefficients d) Embedded Cover Coefficients e) Inverse DWT Cover Coefficients ‘S’

The following assumption and calculated values in the embedding algorithm said in above figure. Numbers of intervals are eight. Median ‘ω’ on HL, LH and HH sub-bans are respectively 0, 1 and 0. Left and right interval widths of HL band are 0.5 and 1.125, LH band are 0.625 and 1 and HH band are 0.125 and 0.825.

After getting Stego image, get cover image and secrete data by applying extracting algorithm on Stego image. Extracting algorithm work as follows. In step 1, performing reading of original image coefficients. Step 2, convert Stego image into DWT coefficients. Step 3, extracting the secrete data and retrieving cover image coefficients.

161	163	162	162	161	158	163	161
161	163	162	162	161	158	163	161
162	163	162	162	161	158	163	162
162	163	162	162	161	158	163	162
161	163	160	161	161	157	164	163
164	166	160	155	161	161	158	159
159	160	162	157	158	164	158	156
159	160	154	159	157	161	156	158

a)

LL				HL			
324.00	324	319	324.00	0	0	0	0
325.00	324	319	325.00	0	0	0	0
327.00	318.00	320	322.00	-3	3	-2.00	5
319	316	320	314.00	0	2.99	2.00	0
-2.00	0	3.00	2.00	0	0	0	0
-1.00	0	3.00	1.00	0	0	0	0
-2.00	2.00	2.00	0	0	-3.00	2.00	1.00
-0.99	0	-5.00	0	0	5.00	-0.99	2.00
LH				HH			

b)

LL				HL			
324.00	324	319	324.00	0	0	0	0
325.00	324	319	325.00	0	0	0	0
327.00	318.00	320	322.00	-1.5	3.35	-1.00	5.50
319	316	320	314.00	0	3.35	2.25	0
0.400	0	4.325	3.25	0	0	0	0
0.60	0	4.325	2.125	0	0	0	0
0.40	3.25	3.25	0	0	-.75	1.8	1.8
0.60	0	-0.537	0	0	4.3	-0.25	2.00
LH				HH			

c)

162	162	162	162	162	157	164	160
162	162	162	162	162	157	164	160
163	162	162	162	162	157	164	161
163	162	162	162	162	157	164	161
163	163	162	159	162	157	165	163
164	164	159	155	161	160	157	159
160	159	162	158	161	162	158	156
160	159	154	158	159	159	156	158

d)

Figure 6 a) Input 8 x 8 Stego Coefficients ‘S’ b) DWT Stego Coefficients c) Extracted Stego Coefficients d) Inverse DWT Stego Coefficients ‘C^{I}’

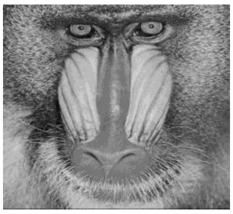
This example produce, MSE value as 1.093 and PSNR value as 95.4832.
If we are applying same procedure on below 512 x 512 images set, then the Stego image quality with respective original as show in below figure 7. Where adaptive quantized intervals are 32.

PSNR:61.9421
Capacity: 124130

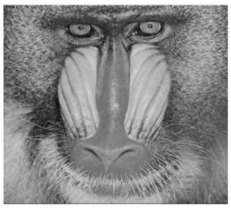
Aerial

PSNR: 75.1145
Capacity: 78319

Airplane



PSNR: 59.8675
Capacity: 145268



Baboon

PSNR: 66.8428
Capacity: 128267

Barbara

PSNR: 64.2846
Capacity: 125149

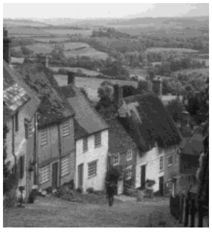
Boat

PSNR: 56.2853
Capacity:99547

Couple

PSNR:71.6899
Capacity:145867

Elaine



PSNR:69.1061
Capacity:131638

Goldhill

PSNR:69.347
Capacity: 108560

Lena

PSNR: 68.9659
Capacity:134813

Pentagon

PSNR: 64.548
Capacity: 96958

Peppers

PSNR:72.2669
Capacity:128845

Truck

PSNR:77.8182
Capacity: 125842

Zelda

Figure 7. Original images, PSNR values at 32-32-32 intervals and Stego images

To measure the quality of a digital image, HVS is the fastest approach. However, although this criterion is effective in general, the result may differ from person to person. To establish an objective criterion for digital image quality, a parameter named PSNR is defined as follows

$$PSNR = 10\log_{10}\frac{255^2}{MSE}$$

where MSE (Mean Square Error) stands for the mean square difference between the cover image and the stego image. The mathematical definition for MSE is as follows

$$MSE = \frac{1}{m*n}\sum_{i=1}^{M}\sum_{j=1}^{N}(a_{ij} - b_{ij})$$

Where a_{ij} and b_{ij} means the pixel value at position (i, j) in the cover image and stego image respectively. The calculated PSNR usually adopts dB value for quality judgment. The larger PSNR is higher image quality and vice-versa. Another measure is used for evaluating the performance of a data embedding scheme is embedding capacity. We define the embedding capacity as the number of bits that can be embedded into the image.

The tabulated results shown in table 1 is comparing non-zero embedding technique between the DWT plus adaptive quantization and DCT plus quantization method, hence for non-zero embedding with DWT and adaptive quantization gives better quality and capacity over DCT and quantization. Then graph 1, shows the comparison between embedding capacity over DWT plus adaptive quantization and DCT plus quantization and graph 2, shows the comparison between PSNR of stego image with respect to original image over DWT plus adaptive quantization and DCT plus quantization. As demonstrate the below figure 5 and 6 adaptive quantization plus DWT is outperformer over uniform quantization plus DCT with respective embedding capacity and stego image quality.

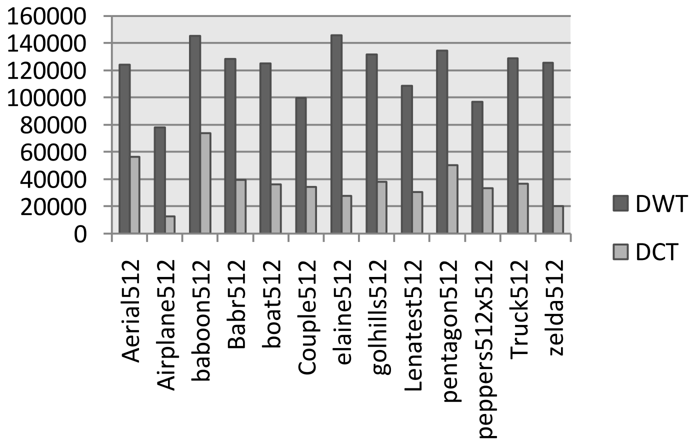


Figure 8. Comparison of embedding capacity

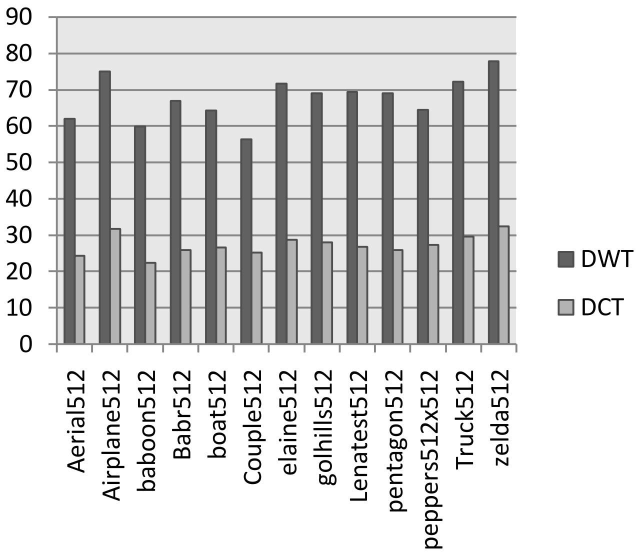


Figure 9. Comparison of PSNR values

Table 1 Performance comparison between DWT embedding and DCT embedding

Image Name	DWT		DCT	
	Capacity	PSNR	Capacity	PSNR
Aerial	124130	61.9421	56564	24.2961
Airplane	78319	75.1145	12608	31.6485
baboon	145268	59.8675	74017	22.3393
Barbara	128267	66.8428	39346	25.8765
Boat	125149	64.2846	36280	26.5561
Couple	99547	56.2853	34362	25.1796
Elaine	145867	71.6899	27556	28.6529
Golhills	131638	69.1061	38188	27.9894
Lena	108560	69.347	30766	26.8517
pentagon	134813	68.9659	50127	25.9769
Peppers	96958	64.548	33617	27.3007
Truck	128845	72.2669	36734	29.6722
Zelda	125842	77.8182	20071	32.3821

V. Conclusion

With the adoption of non-zero coefficient embedding at high frequency sub-bands with help of DWT plus adaptive quantization technique, there is need for stego image quality to prevent from steganalysis methods. And also need for embed large amount of the data within cover image without much added noise into the stego image. Our proposal gives way to the superior quality and embedding capacity with less noise. It also self resist from the steganalysis of LSB substitution.

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