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Secret Communication Based on Quantization Tables

Po-Yueh Chen* and Wei-Chih Chen

Department of Computer Science and Information Engineering,
National Changhua University of Education, Changhua, Taiwan, R.O.C

Abstract: Because of the prevalence of internet, the information security issues have attracted much attention in recent years. Protecting privacy of exchanging information through media becomes the subject of many studies. The Quantization in JPEG is to encode the coefficients transformed by Discrete Cosine Transform (DCT) using a Quantization Table (QT) generated by a quality factor. Quantizing DCT coefficients by different QTs can be adopted to record the secret messages. Based on the variation of QTs, we propose two schemes in frequency domain to improve a data hiding method, in terms of correct extraction rate and image quality. Experimental results show that the proposed approaches can provide better correct extraction rate, higher image quality, and satisfactory embedding capacity.

Keywords: JPEG; Quantizationt table; discrete cosine transform; discrete wavelet transform.

1. Introduction

With the rapid development of Internet, the frequency of transmitting and receiving information over it increases, and the need for secrecy increases as well. In order to protect the information from being stolen and modified during transmission, cryptography is generally applied before transmitting the information. However, it makes the information unnatural and therefore suspicious. Another protection mechanism, called steganography arises as a result. Steganography hides the secret messages into other media instead of encrypting them directly. The media appear similar before and after data hiding and therefore they are not suspicious. Nowadays, the above two mentioned schemes can be integrated by hiding the encrypted information into a carrier media.

For digital images, both spatial domain and frequency domain can be adopted for data hiding. Hiding information in spatial domain is to modify the image pixel values directly [1, 2]. Such methods can hide more information but damages more to image quality as well. Hiding information in frequency domain first transforms the carrier image into frequency domain coefficients by transforms such as Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT). Then the message embedding process is performed on those coefficients, according to the feature of individual sub-band. Finally the modified coefficients are transformed back to spatial domain [3-5]. Frequency domain methods damage less to image quality but hide less information.

Most natural images use JPEG as the storage format. JPEG quantizes DCT coefficients using a Quantization Table (QT) produced by a quality factor [6, 7]. In [8], applying different QTs to

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* Corresponding author; e-mail:pychen@cc.ncue.edu.tw

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DCT coefficients produces different quantization results and hence the secret information can be recorded accordingly. However, the extracted information is not exactly correct. In this paper, we propose two new approaches in frequency domain to improve the scheme in [8]. The first one improves the extracting process so we can extract exactly correct secret information. The second approach integrates DCT with DWT to further improve the image quality by choosing less important sub-bands for hiding information [9, 10].

In Section 2, we review some related technical schemes and definitions. The proposed schemes are described with details in Section 3. Section 4 demonstrates the experimental results and analysis. Finally, the conclusions are provided in Section 5.

2. Related techniques and definitions

In this section, we review some related technical schemes such as DWT, DCT, the JPEG quantization process with QTs, and Arnold Transform. Furthermore, Peak Signal to Noise Ratio (PSNR) and Correct Decoding Rate (CDR) are defined for evaluating the system performance.

2.1. Discrete cosine transform (DCT)

Figure 1 depicts the procedures how DCT transforms an image from spatial domain to frequency domain and vice versa. By subtracting 128 (the mean for gray scaled images) from each pixel in spatial domain, we can obtain zero-mean data. Performing the Forward Discrete Cosine Transform (FDCT), the resulting DCT coefficients are in frequency domain. Similarly, using the DCT coefficients, we can reconstruct the original image by performing the Inverse Discrete Cosine Transform (IDCT) and then adding 128 to each pixel.

The operations for FDCT and IDCT are defined in equations (1) and (2) respectively.

$$D(i,j)=\frac{1}{\sqrt{2N}}C(i)C(j)\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)\cos\left[\frac{(2x+1)i\pi}{2N}\right]\cos\left[\frac{(2y+1)j\pi}{2N}\right] \quad (1)$$

$$f(x,y)=\frac{1}{\sqrt{2N}}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}C(i)C(j)D(i,j)\cos\left[\frac{(2x+1)i\pi}{2N}\right]\cos\left[\frac{(2y+1)j\pi}{2N}\right] \quad (2)$$

where D(i, j) is the value of the coefficient at location (i, j) in frequency domain and f(x, y) is the pixel value at location (x, y) in spatial domain, N is the block size, C(0) =1/ $\sqrt{2}$, C(i) = 1 for i $\neq 0$ and C(j) = 1 for j $\neq 0$.

The distribution of DCT coefficients is shown in Figure 2. The coefficient at location (0, 0) is called the DC coefficient whereas others are called the AC ones. The DC coefficient is the most important one because it represents the base frequency of the entire block. The importance ranking for the AC coefficients is: low frequency > medium frequency > high frequency.

2.2. Discrete Wavelet Transform (DWT)

DWT is an alternative approach for transforming images from spatial domain into frequency domain. We can obtain image data in frequency domain by performing Forward Discrete Wavelet Transform (FDWT). To recover the original image data in spatial domain, Inverse Discrete Wavelet Transform (IDWT) is applied. As shown in Figure 3, the overview is similar to the one for DCT except that there is no offset shifting and the transformations are different. Let us take an image of size 4 × 4 as shown in Figure 4(a) for example. The 2-D Haar DWT (the simplest DWT) performs the following steps:

Step 1: Horizontal split: Perform addition and subtraction between two adjacent columns and then store the sums and differences at the right- and left-hand sides respectively. The resulting values are shown in Figure 4(b).

Step 2: Vertical split: Perform addition and subtraction between two adjacent rows and then store the sums and differences at the upper and bottom parts respectively. The final resulting values are shown in Figure 4(c).

After these two steps, we can split the image into four sub-bands: LL sub-band, HL sub-band, LH sub-band and HH sub-band, as shown in Figure 4(d). The importance ranking of these four sub-bands is LL > HL > LH > HH.

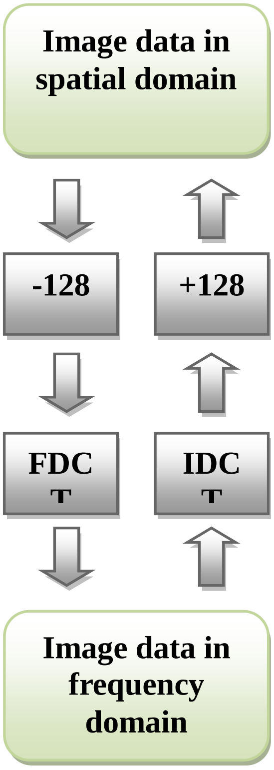


Figure 1. The procedure of performing DCT and IDC

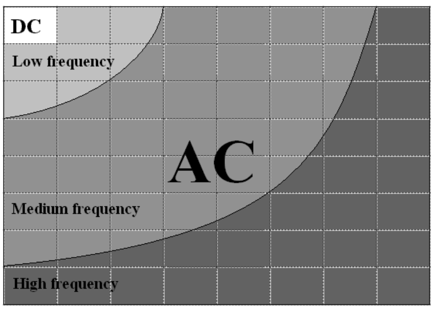


Figure 2. The distribution of DCT coefficients

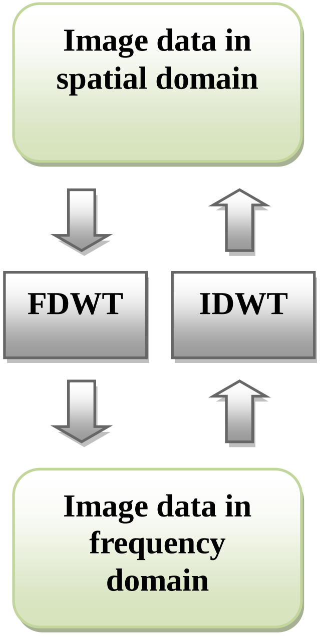
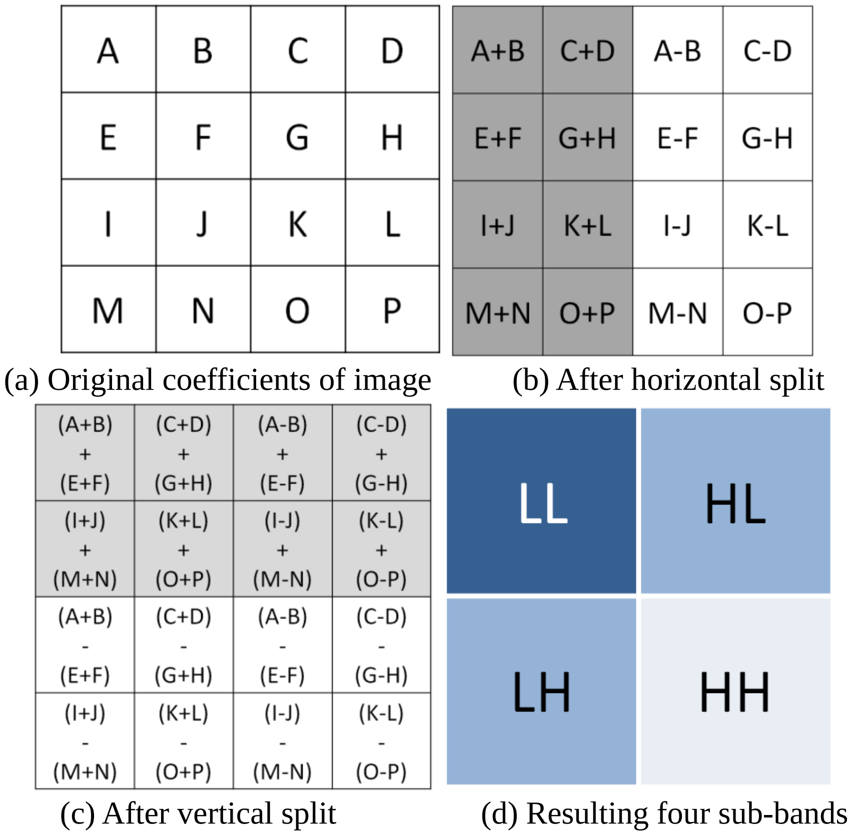


Figure 3. The procedure of performing DWT and IDW



(a) Original coefficients of image (b) After horizontal split

(c) After vertical split (d) Resulting four sub-bands

Figure 4. Steps of Haar DWT

2.3. JPEG quantization

In standard JPEG, quantization, the DCT coefficients are divided by the corresponding QT coefficients one by one, as defined in the following equation:

$$DCT^{Q}(x,y) = Round\left(\frac{DCT(x,y)}{QT(x,y)}\right) \tag{3}$$

where QT(x, y) stands for the QT coefficients of a QT, DCT(x, y) and $DCT^{Q}(x, y)$ are the original DCT coefficients and the quantized DCT coefficients, respectively. The Round() function rounds the ratio to the nearest integer.

The adjustment equations of JPEG QTs are defined as follows:

$$S = \begin{cases} 200 - 2Q, & 50 \le Q < 100 \\ \dfrac{5000}{Q}, & 1 \le Q < 50 \end{cases} \tag{4}$$

$$T_S(i,j) = \begin{cases} 1, & Q = 100 \\ \left\lfloor \dfrac{S \times T_b(i,j)}{100} \right\rfloor, & 1 \le Q < 100 \end{cases} \tag{5}$$

where Tb(i, j) and Ts(i, j) are the base QT and the scaled QT, respectively. Each element of Ts can be computed with an element of Tb and a scaling factor S. Figure 5 shows the content of the JPEG base QT. Applying equation (4), the scaling factor S can be calculated with a quality factor Q, $1 \le Q \le 100$. The value of Q can be set by a user according to his individual image quality demand. Greater Q indicates better image quality, higher quantization level, and smaller QT coefficients. For example, Ts(i, j) = Tb(i, j) if Q = 50 whereas Ts(i, j) = 1 if Q = 100. Figure 6 demonstrates an example of JPEG compression using DCT.

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Figure 5. The base QT (JPEG standard luminance QT)

180	183	186	189	192	195	198	199
181	186	187	188	191	193	195	198
183	182	184	185	187	192	197	199
183	184	186	185	190	181	183	185
175	180	181	185	187	190	193	192
177	179	182	183	184	189	194	195
175	174	178	181	183	184	187	190
172	177	180	182	184	185	189	191

Image block

-128 → **FDCT**

468	-43	2	-3	-1	0	0	0
23	0	0	1	0	-1	0	0
-3	-2	-3	-2	0	0	0	0
0	-2	-1	0	0	1	0	0
1	0	-3	0	0	0	0	0
-1	0	0	0	1	0	1	1
2	-3	2	0	-1	1	0	0
-4	-1	0	1	1	2	0	0

Results after FDCT

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Quantization table

Quantizatio n

29	-3	0	0	0	0	0	0
1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Quantization results

Figure 6. An example of JPEG compression using DCT

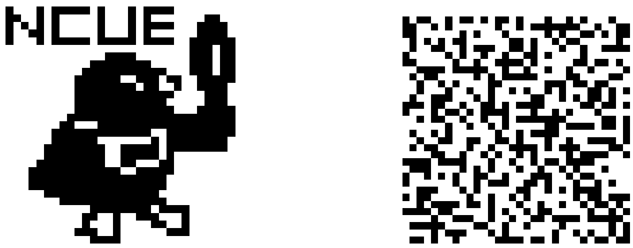
2.4. Arnold transform

Arnold Transform is a tool for scrambling an image. The equation is defined as follows:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \mod N \tag{6}$$

where (x, y) is the original location of a pixel and (x', y') is the location of the pixel after scrambling. N is the image size.

The times of scrambling can be a key to recover the original image. Figure 7 shows a 32 × 32 image and the one scrambled 10 times by Arnold Transform.



(a) Original image (b) Scrambled image

Figure 7. An example of Arnold Transform

2.5. Peak signal to noise ratio and correct decoding rate

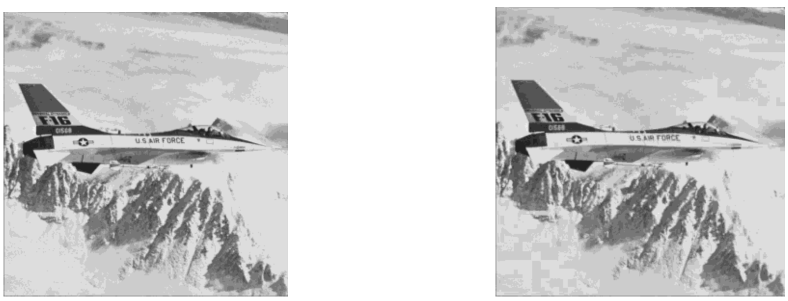
To evaluate the image quality of a grey image after certain image processing, the Peak Signal to Noise Ratio (PSNR) is adopted as an objective parameter. PSNR is defined as follows:

$$PSNR = 10 \log_{10} \frac{255^2}{MSE} \tag{7}$$

where MSE is the Mean Square Error between two image of size M × N and defined as:

$$MSE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (x_{ij} - x'_{ij})^2 \tag{8}$$

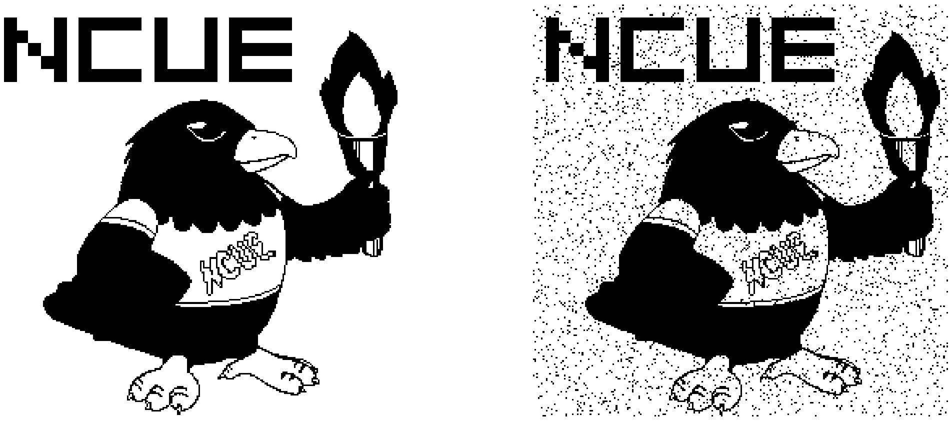
where x_{ij} and x'_{ij} are the pixel values at position (i, j) for the original image and the image after processing, respectively. Figure 8 illustrates a practical example for an image of size 512 × 512. In general, it is difficult for human eyes to identify the difference if the PSNR is greater than 30dB.



(a) Original image (b) Image after processing (PSNR = 35dB)

Figure 8. An example of PSNR

For binary (black and white) images, Correct Decoding Rate (CDR) is defined as a ratio of correct pixel number to total pixel number, in percentage. A CDR of 100% indicates that the image after processing is exactly the same as the original one. Figure 9 shows an example of CDR=95.8% where the image is of size 128 × 128.



(a) Original image (b) Image after processing (CDR = 95.8 %)

Figure 9. An example of CDR

3. Proposed schemes

Based on QT manipulations, we proposed a modified scheme in subsection 3.1 to achieve 100% CDR. DWT is integrated for improving the PSNR in subsection 3.2.

3.1. The DCT-based approach: maintaining 100% CDR

Suppose the secret information to be embedded, namely S, is a binary image of size $S_L \times S_W$, the host image H is a gray image of size $H_L \times H_W$, and S is proportional to H as indicated in the following equation:

$$\frac{H_L}{S_L} = \frac{H_W}{S_W} \tag{6}$$

The message embedding includes the following steps:

Step 1: Divide H into non-overlapping blocks H(m, n) of size $\frac{H_L}{S_L} \times \frac{H_W}{S_W}$.

Step 2: $\begin{cases} \text{If } S(m,n) = 0, H(m,n) \text{ is quantized by Q2.} \\ \text{If } S(m,n) = 1, H(m,n) \text{ is quantized by Q1.} \end{cases}$

Step 3: $\begin{cases} \text{If } S(m,n) = 0, H(m,n) \text{ is de-quantized by Q2.} \\ \text{If } S(m,n) = 1, H(m,n) \text{ is de-quantized by Q1.} \end{cases}$

Step 4: Obtain the stego image H' by assembling H(m, n).

In the above steps, Q1 and Q2 are two quality factors determined by both the transmitter and

the receiver. The message extracting includes the following steps:
Step 1: Quantize $H^{'}$ and then de-quantize to get $H^{'}_{Q2}$, using Q2.
Step 2: Subtract $H^{'}_{Q2}$ from $H^{'}$ to obtain D.
Step 3: Divide D into non-overlapping blocks of the same size as embedding.
Step 4: Calculate the number of ‘0’ in each block.
Step 5: Set a threshold.
Step 6: If the number of ‘0’ in a block is greater than the threshold, extract a ‘0,’ otherwise, extract a ‘1.’
Step 7: Obtain the overall secret information.

According to step 2 of embedding/extracting, the coefficient differences in the blocks quantized by Q2 should be ‘0’. As a result, in step 4 of extracting, we can identify whether the block is quantized by Q1 or Q2 by calculating the number of ‘0’. The threshold in step 5 is commonly obtained by experimental statistics and is about 3/4 of the block size. The overall procedure is shown in Figure 10. Figure 11 demonstrates an example of the DCT-based approach, where 11(a)-(f) respectively associate the host image of size 512 × 512, the secret image of size 32 × 32, the secret image after scrambling 10 times by Arnold Transform, the stego image with PSNR = 37.7 dB, the extracted secret image and the recovered secret image with CDR = 100.0 %. In Figure 11, the quality factors are Q1 = 100 and Q2 = 70.

3.2. DWT-DCT approach: improving the image quality

If image quality is the key concern of a user and 100% CDR is not required, we can slightly sacrifice CDR for better PSNR. In order to improve the PSNR of stego images, we first apply DWT to the host image and then DCT to the resulting DWT sub-bands. To human eyes sensitivity, the importance ranking of DWT sub-bands is LL > HL > LH > HH. Therefore, to maintain better image quality, the recommended embedding order is HH, LH, HL, and finally LL. Figure 12. shows the procedure of the DWT-DCT approach. Figure 13. shows an example of the DWT-DCT approach, where 13(a)-(f) respectively associate the host image of size 512 × 512, the secret image of size 32 × 32, the secret image after scrambling 10 times by Arnold Transform, the stego image with PSNR = 45.9 dB, the extracted secret image and the recovered secret image with CDR = 98.4 %. In Figure 13. the quality factors are Q1 = 100 and Q2 = 90, and the secret image is embedded in LL sub-band..

4. Experimental results

The host image is a 512 × 512 gray image and the size of secret image changes from one experiment to another. To evaluate the image quality of a stego image and the correctness of extracting, we adopt the PSNR and the CDR, respectively.

Tables 1 and 2 respectively list the resulting CDR and PSNR with different values of Q1 and Q2. We can observe in Tables 1 and 2 that when (Q1-Q2) is bigger, the CDR is higher and the PSNR is lower. In addition, the CDR can reach 100% using the proposed schemes if (Q1-Q2) ≥ 30. Figures 14 and 15. show the line graphs of Tables 1 and 2, respectively.

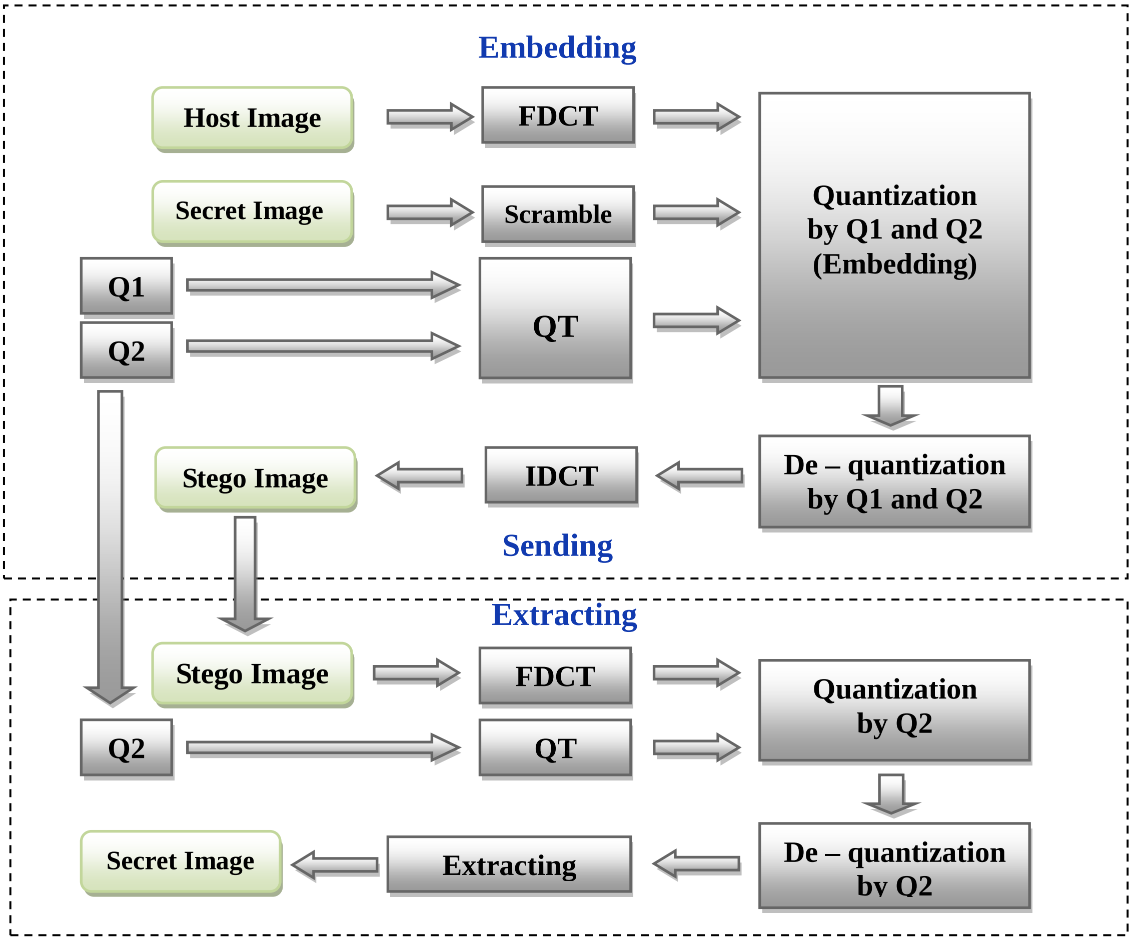


Figure 10. The flow chart of the DCT-based approach

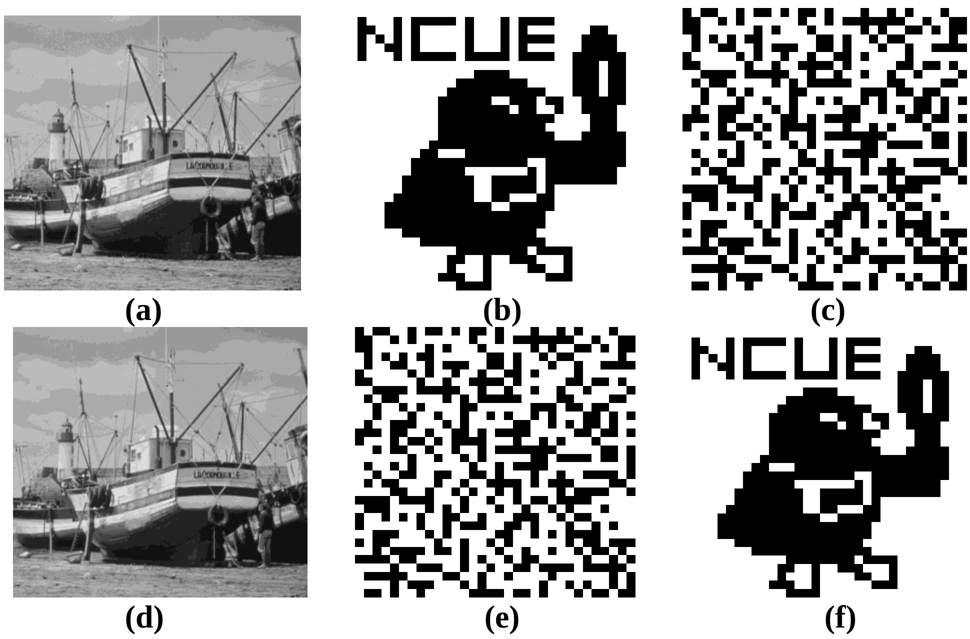


Figure 11. An example of the DCT-based approach

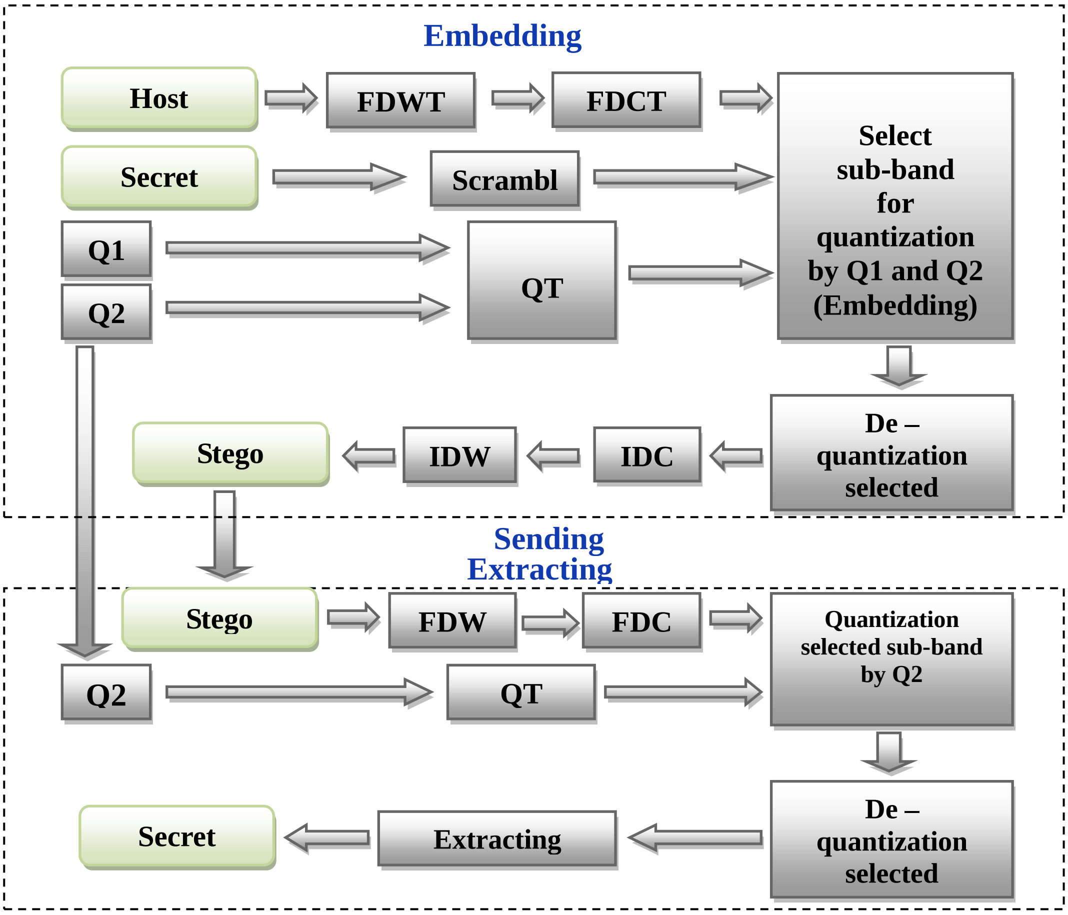


Figure12. The flow cha t of the DWT-DCT approach

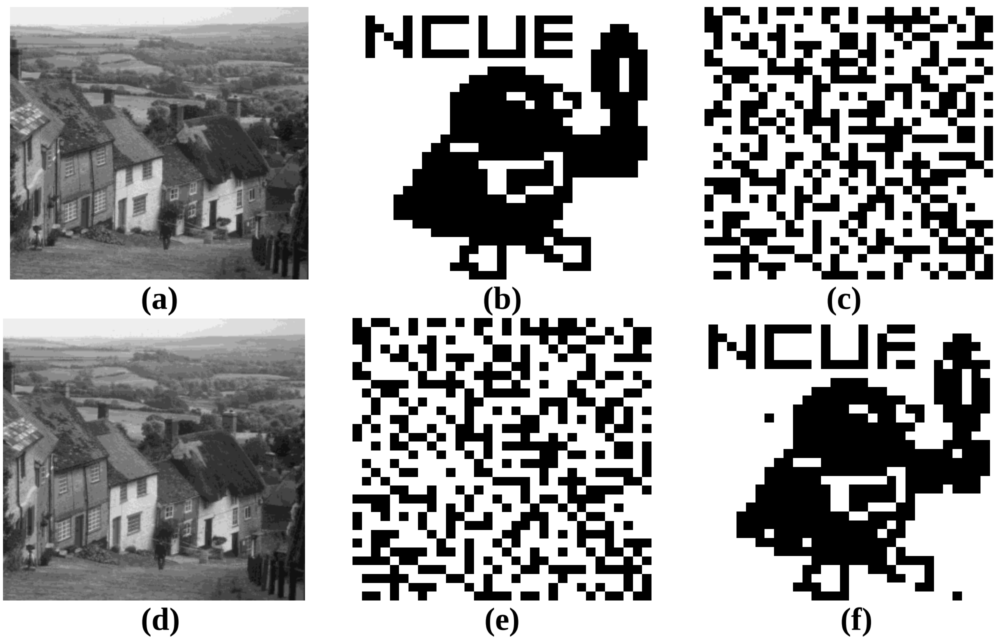


Figure 13. An example of the DWT-DCT approach

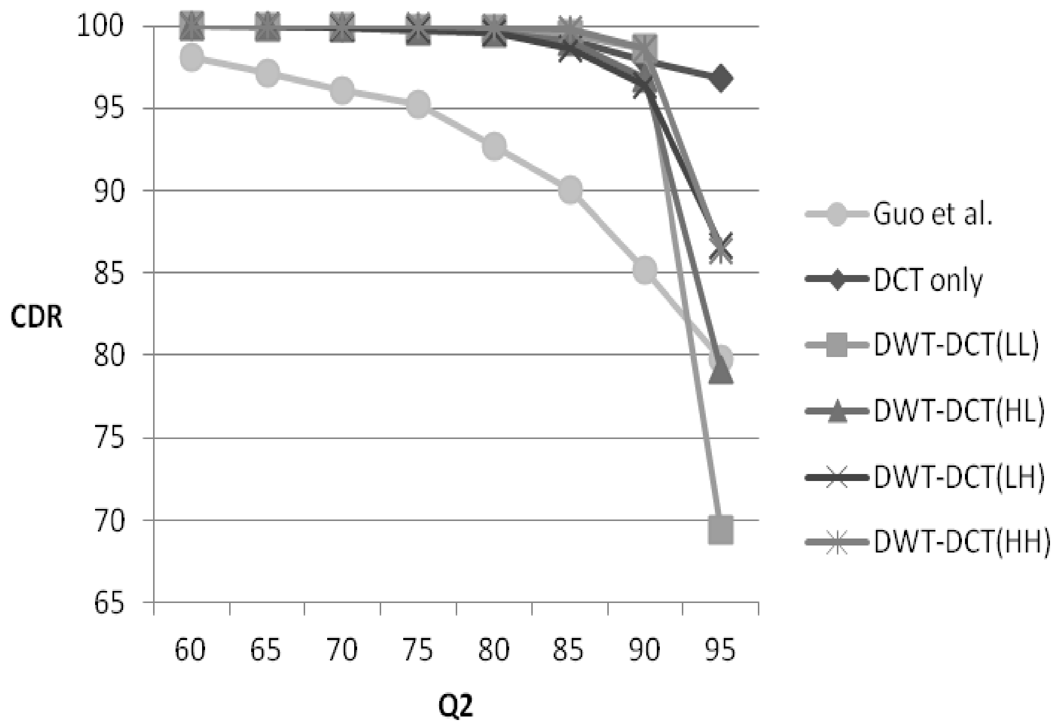


Figure 14. Line graphs of Table 1

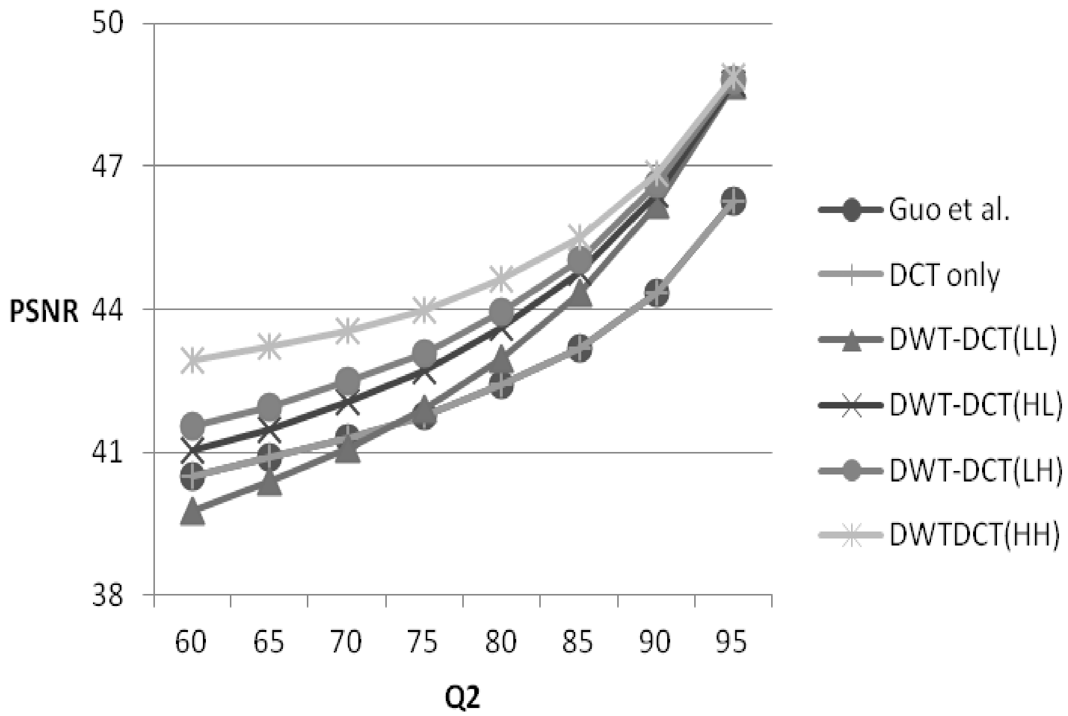


Figure 15. Line graphs of Table 2

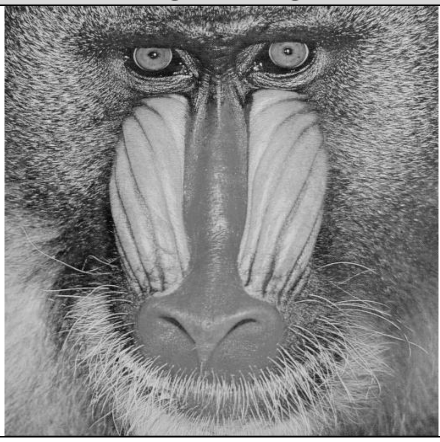
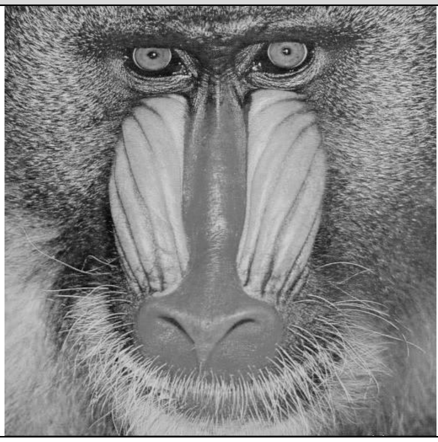
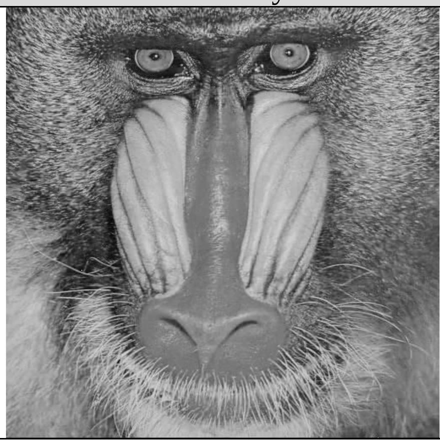
Table 1. CDR with different values of Q1 and Q2

Q1	Q2	CDR					
		Guo et al.[8]	Proposed Schemes				
			DCT only	DWT-DCT			
				LL	HL	LH	HH
100	60	98.1	100.0	100.0	100.0	100.0	100.0
100	65	97.2	100.0	100.0	100.0	100.0	100.0
100	70	96.1	100.0	99.9	99.9	99.9	100.0
100	75	95.3	99.9	99.8	99.7	99.8	100.0
100	80	92.7	99.7	99.8	99.6	99.6	99.9
100	85	90.1	99.1	99.5	99.1	98.6	99.8
100	90	85.2	97.9	98.6	96.8	96.5	98.7
100	95	79.8	96.8	69.4	79.1	86.7	86.3

Table 2. PSNR with different values of Q1 and Q2

Q1	Q2	PSNR					
		Guo et al.[8]	Proposed Schemes				
			DCT only	DWT-DCT			
				LL	HL	LH	HH
100	60	40.5	40.5	39.8	41.0	41.6	42.9
100	65	40.9	40.9	40.4	41.5	42.0	43.2
100	70	41.3	41.3	41.1	42.0	42.5	43.6
100	75	41.8	41.8	41.9	42.7	43.1	44.0
100	80	42.4	42.4	43.0	43.6	43.9	44.6
100	85	43.2	43.2	44.3	44.8	45.0	45.5
100	90	44.3	44.3	46.2	46.4	46.6	46.9
100	95	46.5	46.3	48.7	48.7	48.8	48.9

Table 4. Examples of three samples\

Baboon	Original image	
		
	PSNR = ---- dB	
	DWT-DCT	DCT only
		
	PSNR = 39.6 dB	PSNR = 37.5 dB
Lena	Original image	
		
	PSNR = ---- dB	PSNR = 43.8 dB

Continued from Table 4.

	DWT-DCT	DCT only
		
	PSNR = 45.3 dB	PSNR = 43.8 dB
Pepper	Original image	
		
	PSNR = ---- dB	
	DWT-DCT	DCT only
		
	PSNR = 44.5 dB	PSNR = 43.0 dB

Table 5. Proposed Scheme (DCT only) under attacks

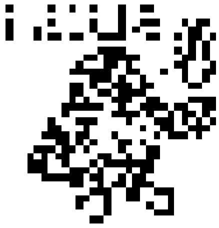
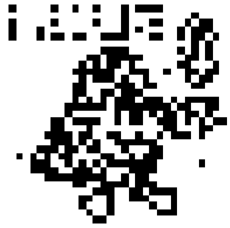
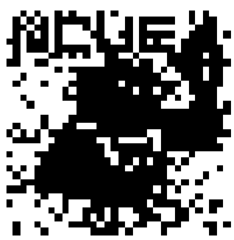
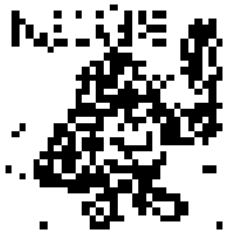
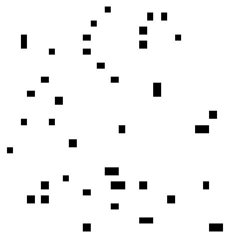
No attack	Sharp	Noise	Filter
			
			
CDR = 100.0%	CDR = 83.0%	CDR = 57.4%	CDR = 85.0%
Crop	Resize	JPEG compression	
			
			
CDR = 85.5%	CDR = 80.0%	CDR = 85.0%	

Table 6. Proposed Scheme (DWT-DCT) under attacks

No attack	Sharp	Noise	Filter
			
			
CDR = 100.0%	CDR = 85.5%	CDR = 57.5%	CDR = 79.3%
Crop	Resize	JPEG compression	
			
			
CDR = 84.5%	CDR = 79.6%	CDR = 93.0%	

5. Conclusions

In this paper, we propose two secret communication schemes in frequency domain based on JPEG QTs. The first one improves the extracting process to extract the 100% correct secret image. To improve the image quality of the resulting stego image, the second scheme integrates DCT with DWT. Experimental results show that our schemes can achieve superior CDR and PSNR. We tested the robustness of the proposed schemes as well. The results indicate that they perform well while encountering most of the common attacks. When facing attacks such as noise and resize, there is still some space for improvement though.

References

[1] Zhang, X. 2011. Reversible Data Hiding in Encrypted Image, *IEEE Signal Processing Letters*, 18: 255-258.

[2] Fallahpour, M., Megias, D. and Ghanbari, M. 2011. Reversible and High-capacity Data Hiding in Medical Images, *IET Image Processing*, 5: 190-197.

[3] Lai, C.C. and Tsai, C.C. 2010. Digital Image Watermarking Using Discrete Wavelet Transform and Singular Value Decomposition, *IEEE Transactions on Instrumentation and Measurement*, 59: 3060-3063.

[4] Yusof, Y. and Khalifa, O.O. 2008. Imperceptibility and Robustness Analysis of DWT-based Digital Image Watermarking, *Proc. International Conference on Computer and Communication Engineering*, Malaysia, May 2008.

[5] Khan, M.I., Jeoti, V. and Malik, A.S. 2011. Designing a Joint Perceptual Encryption and Blind Watermarking Scheme Compliant with JPEG Compression Standard, *Proc. International Conference on Computer Applications and Industrial Electronics*, Malaysia, March 2011.

[6] Almohammad, A., Hierons, R.M. and Ghinea, G. 2008. High Capacity Steganographic Method Based Upon JPEG, *Proc. of 3rd IEEE International Conference on Availability, Reliability and Security*, Barcelona, Spain, May 2008.

[7] Kornblum, J.D. 2008. Using JPEG Quantization Tables to Identify Imagery Processed by Software, *Digital Investigation*, 5: 21-25.

[8] Guo, J.M. and Le, T.N. 2010. Secret Communication Using JPEG Double Compression, *IEEE Signal Processing Letters*, 17: 879 -882.

[9] Liu, P.F., Liang, B.Z., and Peng, C. 2010. A DWT-DCT Based Blind Watermarking Algorithm for Copyright Protection, *Proc. of 3rd IEEE International Conference on Computer Science and Information Technology*, Beijing, China, September 2010.

[10] Wang, N., Wang, Y., and Li, X. 2009. A Novel Robust Watermarking Algorithm Based on DWT and DCT, *Proc. of International Conference on Computational Intelligence and Security*, Beijing, China, December 2009.