

CROSS-FREQUENCY DOMAIN FOR JPEG INVERSIBLE WATERMARKING USING MULTIPLE QUANTIZATION TABLES

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Abstract

Reversible data hiding techniques for JPEG images have big challenges in order to improve the capacity, quality, and flexible embedding method. In this article, we propose a new cross-domain using combination of multiple quantization tables in JPEG algorithm. We survey the efficiency of quantization coefficients on the DCT tables in order to decide the way to embed the watermark information. Compared to the conventional method, our experimental results show that our proposed method has better performance in term of both the increasing capacity and improving the quality of embedded JPEG images after data embedding.

Index terms

DCT coefficients, quantization tables, reversible watermark, cross-domain frequency, JPEG algorithm.

1. Introduction

1.1. Overview

In literature, reversible data hiding techniques (RDH) is a solution allowing users to hide a payload of secret information into their multimedia contents for generating the embedded contents. In this solutions, both of the original cover contents and secret information can be recovered by using the embedded contents without distortion. Therefore, these important techniques are usually employed in medical imagery, military imagery and law forensics because of the original images cannot be adjusted or damaged after extracting the secret information [1], [2].

In order to apply the RDH methods on real applications, some researchers have proposed RDH algorithms for JPEG (Joint Photographic Experts Group) image^a. The RDH method in the JPEG image is useful for image integrity, image authentication, and image privacy. Such RDH for JPEG image is needed to consider the following

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problems: (1) The capacity of the hiding information is limited; (2) The visual quality of JPEG image is lower than that of uncompressed image; (3) The size of embedded JPEG image may be increased more than the original one. That's why the RDH for JPEG image is a challenge comparing with that for the uncompressed image.

In general, data hiding algorithms have become a crucial tool in safeguarding information. Here is an analysis of the pros and cons associated with three popular algorithms used for data hiding: spread code, RDH algorithm, and DCT transform algorithm for JPEG images.

	Advantage	Defect
Spread spectrum code 1001[3]	<ul style="list-style-type: none"> - High sustainability, difficult to destroy. - Can be applied to many different types of signals. - Supports noise reduction and error levels using channel coding techniques. - No decoding is required to identify hidden bits. 	<ul style="list-style-type: none"> - Requires broadband for signal-incremental transmission. - It is necessary to use the synchronization method to determine the distance between the original signal and the hidden signal. - Can detect when attack by popular analysis methods.
RDH algorithm 1001[4], [5]	<ul style="list-style-type: none"> - Minimizing the original data change, helping to preserve the original image quality. - No decoding is required to identify hidden bits. - High sustainability, difficult to destroy. 	<ul style="list-style-type: none"> - Effectively only works with JPEG image files whose size is greater than or equal to the size of the data to be hidden - Hiding information may reduce the quality of the original image file. - Not resistant to decryption attacks.
DCT algorithm [6]	<ul style="list-style-type: none"> - Provides data compression, which saves power during storage. - Can be applied to many different types of images and data files. - User-friendly, easy to use and deploy. 	<ul style="list-style-type: none"> - Cannot accommodate large amounts of touch data. - Information hiding algorithms using DCT can be discovered by comparing DCT blocks between the original file and the hidden file.

Above algorithms show that each has advantage and disadvantage, however, RDH can be used to protect the information inside the digital contents.

1.2. Main contributions

In this article, we focus on proposing the RDH algorithm for JPEG image by using the cross-domain combined multiple quantization tables from JPEG. The contributions in this article are summarized as follows:

(i) Based on the method of Tian [7], we improve the quality of JPEG image after embedding information. Multiple quantization tables of JPEG are surveyed in order to apply it for inversible watermarking. Instead of embedding the information into LSB of DCT coefficients, we also embed the bits information into all bits of DCT coefficients in which the number of nonzero DCT coefficient equals "0". In our method, we survey the efficiency of each quantization table of each component from JPEG algorithm to choose the appropriate DCT coefficients applying our proposed RDH method.

(ii) We suppose that most high frequency of nonzero DCT coefficients affect the quality of embedded JPEG images. Therefore, if we choose less effective DCT coefficients region, we can increase the embedding capacity and then maintain the quality of JPEG images.

1.3. Roadmap

The rest of this article is organized as follows. Section 2 presents a brief review of related works. The RDH of JPEG algorithm is described in section 3. Then, the proposed method is presented in section 4. In section 5, the experimental results are presented to show the efficiency of our method. Finally, we conclude the article in section 6.

2. Related works

In this section, the Difference Expansion (DE) method proposed by Tian [7] and the reduced difference expansion (RDE) method proposed by Liu et al. [8] are reviewed as follows.

2.1. Difference expansion

In the embedding method proposed by Tian [7], first calculate the average value m and difference d of adjacent pixel values (x, y) , as follows:

$$m = \left\lfloor \frac{x + y}{2} \right\rfloor, d = x - y \quad (1)$$

To embed secret data $b \in \{0, 1\}$, compute the extension difference d' as follows:

$$d' = 2 \times d + b \quad (2)$$

To prevent overflow or underflow, d' should satisfy as follows:

$$\begin{cases} |d'| \leq 2 \times (255 - m) & \text{if } 128 \leq m \leq 255 \\ |d'| \leq 2 \times m + 1 & \text{if } 0 \leq m \leq 127 \end{cases} \quad (3)$$

Finally, compute the stego-pixel values x' and y' , as follows:

$$x' = m + \left\lfloor \frac{d' + 1}{2} \right\rfloor, y' = m - \left\lfloor \frac{d'}{2} \right\rfloor \quad (4)$$

To extract the embedded information, first calculate the average m' and difference d' of the adjacent stego-pixel values, as follows:

$$m' = \left\lfloor \frac{x' + y'}{2} \right\rfloor, d' = x' - y' \quad (5)$$

Then, to extract the embedded secret data b , use the following equation:

$$b = LSB(d') \quad (6)$$

Restore the original pixel values (x, y) by calculating the original difference d .

$$d = \left\lfloor \frac{d'}{2} \right\rfloor, x = m + \left\lfloor \frac{d+1}{2} \right\rfloor, y = m - \left\lfloor \frac{d}{2} \right\rfloor \quad (7)$$

2.2. Reduced difference expansion

As shown in article of Liu et al. [8], in the embedding method, they first calculate the average value m and difference d of adjacent pixel values (x, y) , as follows:

$$m = \left\lfloor \frac{x+y}{2} \right\rfloor, d = x - y \quad (8)$$

When the difference value d is greater than "1", they use a logarithmic transformation function to reduce the pixel pair's difference, before calculating the difference d . However, if the difference value d is "0" or "1", the value remains unchanged.

$$d' = \begin{cases} d & \text{if } d < 2 \\ d - 2^{\lfloor \log_2 d \rfloor - 1} & \text{otherwise} \end{cases} \quad (9)$$

In this article, in order to restore the original difference values, a location map (LM) is calculated which is the overhead information to record the changes of pixels.

$$LM = \begin{cases} 0 & \text{if } 2^{\lfloor \log_2 d' \rfloor} = 2^{\lfloor \log_2 d \rfloor}, \\ 1 & \text{if } 2^{\lfloor \log_2 d' \rfloor} \neq 2^{\lfloor \log_2 d \rfloor}. \end{cases} \quad (10)$$

To embed the secret data $b \in \{0, 1\}$, compute the extension difference d'' as follows:

$$d'' = 2 \times d' + b \quad (11)$$

Finally, compute the stego-pixel values x' and y' as follows:

$$x' = m + \left\lfloor \frac{d''+1}{2} \right\rfloor, y' = m - \left\lfloor \frac{d''}{2} \right\rfloor \quad (12)$$

In the extraction phase, first calculate the average m' and difference d'' of the adjacent stego-pixel values as follows:

$$m' = \left\lfloor \frac{x'+y'}{2} \right\rfloor, d'' = x' - y' \quad (13)$$

Extract the secret data b :

$$b = \text{LSB}(d'') \quad (14)$$

Then calculate the difference d' :

$$d' = \left\lfloor \frac{d''}{2} \right\rfloor \quad (15)$$

Use LM to recover the original difference d as follows:

$$d = \begin{cases} d' + 2^{\lfloor \log_2 d' \rfloor - 1} & \text{if } LM = 1, \\ d' + 2^{\lfloor \log_2 d' \rfloor} & \text{if } LM = 0. \end{cases} \quad (16)$$

Then calculate the original pixel values (x, y) :

$$x = m + \left\lfloor \frac{d+1}{2} \right\rfloor, y = m - \left\lfloor \frac{d}{2} \right\rfloor \quad (17)$$

In the applications using multi-layer embedding, DE method may cause the image quality to drop drastically. Therefore, a multi-layer shiftable block strategy has been proposed with the aim of further improving the image quality. Also, above algorithms (*e.g* DE and RDE) can be applied on JPEG algorithm since it is suitable for DCT coefficients domain.

3. RDH of JPEG algorithm

Overview of JPEG algorithm is shown in Fig. 1. Normally, there are three steps including the algorithm, namely, discrete fourier transform (DCT), quantized, and entropy encoder. Firstly, the original image is divided into non-overlapping 8×8 blocks, then is fed into 2D forward DCT (FDCT) function. The obtained DCT tables are quantized by quantization tables. Finally, the quantized coefficients are applied using the Huffman tables in order to generate the entropy coding. Each component of luminance component, the chrominance components are called as Y , and (C_r, C_b) component. In order to compress the components of JPEG image, each component is quantized by using the according quantization table, called Q_y, Q_{cr} , and Q_{cb} . The quantization coefficients effect directly on the quality of JPEG image. Therefore, to further reduce the distortion of JPEG image, we survey the affect of quantized process on DCT coefficients for making the strategy of selection the quantization coefficients for information embedding.

RDH algorithm applying on JPEG image is quite hard to implement because of less compressed information domain for embedding. Some RDH algorithms are proposed for JPEG image, however, it has several demerit points on JPEG domain.

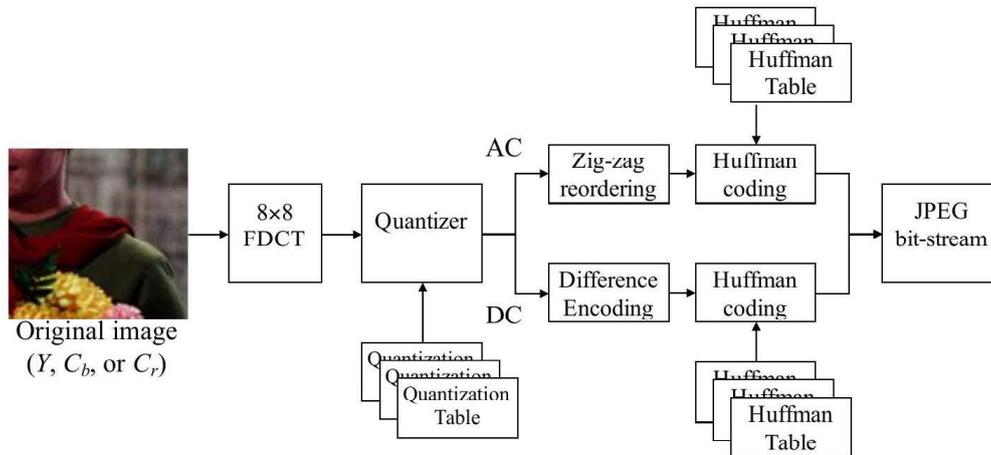


Fig. 1. Algorithm of JPEG.

The first one is the limitation of information embeddable domain. As the results of survey in article [9], the secret information can be embedded on DCT domain and Huffman coding stream of JPEG image. Such embeddable domain also needs to choose carefully for archiving high quality of the embedded JPEG image.

The second one is fragile quality of JPEG image. That means it is quite sensitive for quality of JPEG image to adjust the number of DCT coefficients. Therefore, the choice of DCT coefficients is considered clearly for embedding.

Three categories are well-known such as lossless compression appending scheme [2], difference expansion [7] and histogram shift [10], respectively. Such algorithms are normally applied on the grayscale or color images. Recently, the combination of RDH methods are also considered in order to achieve more efficient such as prediction errors (PEs) proposed in articles [11]–[13].

Most of RDH algorithms are proposed easily on image data, including gray images [14]–[16]. In color-based images, the luminance component, the chrominance component, and RGB channels are employed to control the color domain for hiding the large capacity of information [17]–[19]. However, the color-based RDH methods drive to destroy color images irreversibly. That is why it cannot restore images without any loss in some cases. Therefore, the RDH methods for images should choose the robust features, appropriate regions for embedding the secret digital information.

One more problem of RDH methods for images is computing cost of recovery algorithm [20], [21]. That makes them difficult to apply on the practical applications. Therefore, only applications like medical imaging, military imaging, which the distortion is not desired, the RDH methods can be applied on.

According to the explanation above, we conclude that the RDH algorithm is important for real application, especially for JPEG image.

4. Proposed method

This article also focuses on the proposal to increase the capacity of RDH method by exploiting the feature of JPEG image. We employ the quantization table Q_y, Q_{cb}, Q_{cr} because each of them is defined by the specified quality factor QF .

The influence of Q_y, Q_{cb}, Q_{cr} on the values of the DCT coefficients is under investigation. The total count of non-zero DCT coefficients in the entire JPEG image, denoted as $N_z(i, j)$, is determined. Here, (i, j) represents the coordinates of the quantization coefficients $Q_t(i, j)$ (t being y, cb, cr) in the quantization table Q_y, Q_{cb}, Q_{cr} . This article focuses on surveying the impact of luminance quantization tables in JPEG images.

We suppose that the quantization coefficients $Q_t(i, j)$ have great impact on large number of nonzero DCT coefficients of the whole JPEG image. Therefore, if the secret information W is embedded into the quantization coefficients $Q_t(i, j)$ that have less impact on the DCT coefficients of JPEG image, we can improve the capacity while maintaining the quality of JPEG image.

In order to show the influence of table Q_y, Q_{cb}, Q_{cr} on the values of the DCT coefficient, the count of non-zero DCT coefficients in the Girl image was investigated. Fig. 2 shows the frequency of nonzero DCT coefficients from whole Y component of Girl image.

Based on the result of Fig. 2(b), we consider that if $N_z(i, j) = 0$, the according quantization coefficients $Q_t(i, j)$ have no impact on the quality of JPEG image. The reason is that according to the algorithm of JPEG image, the zero DCT coefficients have no meaning in the quantization process.

If $N_z(i, j) \leq T_q$ (T_q is the prefix threshold), the according quantization coefficients $Q_t(i, j)$ have less impact on the quality of JPEG image.

Based on above investigation, we propose new RDH by using quantization table embedding as follows:

4.1. Embedding method using weights for quantization table

The embedding domain of our proposed method is shown in Fig. 2(a). Our weights for quantization table (WQTB) focuses on the low-frequency and middle-frequency domain for normal embedding of Tian's method. Additionally, our method also includes the quantization tables domain for increasing the capacity.

Since the value of DCT coefficients from high frequency domain of JPEG image is almost zero, we decide to embed $(i + j)/2$ bits into the quantization coefficients.

We expect that the embedding method applying on the quantization coefficients for zero DCT coefficients (high frequency domain) will not degrade the quality of JPEG image so much. That makes our method can improve the capacity and quality.

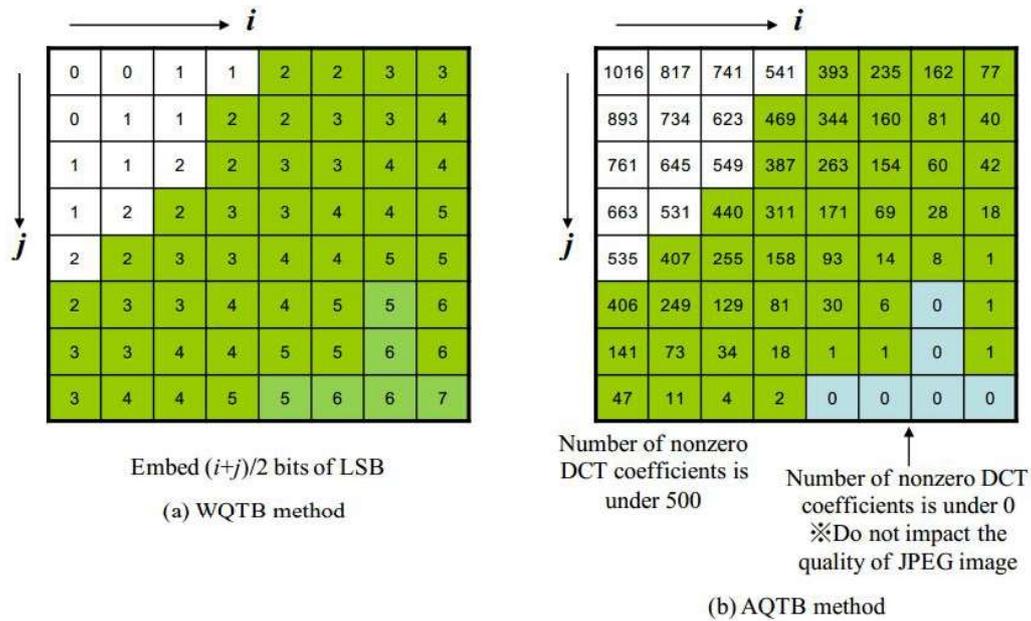


Fig. 2. Number of nonzero DCT coefficients of Girl image.

4.2. Embedding method using frequency of nonzero DCT coefficients

To avoid degrading the quality of the JPEG image, we examine factors that have no impact on the quality of the embedded image.

The idea is shown in Fig. 2(b). We calculate the number of all zero DCT coefficients from each position (i, j) of quantization tables (AQTB), called $N_z(i, j)$. After specifying $N_z(i, j)$, our method embeds the information into the quantization coefficients $Q_t(i, j)$ as follows:

- If $N_z(i, j) = 0$, replace $Q_t(i, j)$ with 8 bits of secret information from W .
- If $N_z(i, j) < T_q$, embed the information bit b into the LSB of $Q_t(i, j)$.
- If $N_z(i, j) \geq T_q$, no embedding.

The embedding method from the article [7] is employed. The detail of embedding method can be referred from article [7]. Our improvement method employs additionally the method mentioned from section (2.1) and section (2.2). That makes our method difference. Our proposed method guarantees that the capacity and the quality of JPEG image after the information embedding can be improved effectively.

5. Experimental results

The efficiency of the proposed method is evaluated using eight images in Fig. 3, each with a size of 512×512 . These images, namely "airplane," "barbara," "boat," "fruits,"

"goldhill," "lena," "peppers," and "zelda," are compressed using the IJG toolbox^b with a quality factor of $QF = 75$. The secret message bits are extracted from the grayscale logo shown in Fig. 3(i), which has a size of 32×32 . The empirically set threshold T_q is 500, determined based on the survey of the frequency of nonzero DCT coefficients displayed in Fig. 2(b). In the low-frequency area, the number of nonzero DCT coefficients is consistently greater than 500. Consequently, embedding information into the low-frequency region may negatively impact the quality of the JPEG image. For future work, it is necessary to determine the appropriate threshold T_q for larger image databases.

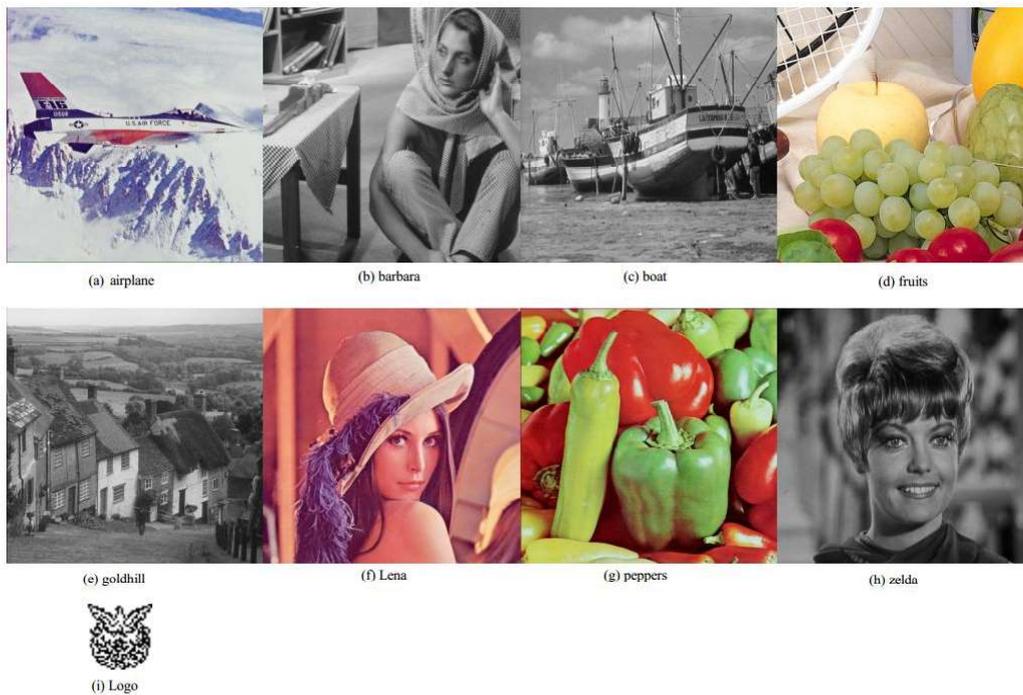


Fig. 3. Eight test images.

We embed the logo in Fig. 3(i) into the test JPEG images based on Tian algorithm, that with our AQTb, and that with our WQTb. After embedding information, we calculate the capacity of those experiments and compare each others.

The results of the proposed method is shown in Table 1. According to the our comparison, the capacity of our proposed method can be improved since the methods can exploit the region that does not impact to the quality of JPEG image for embedding. It proves that the proposed method has better performance in term of increasing capacity of embedded JPEG.

^b<https://jpeg.org/>

Table 1. Comparison of capacity (bits)

JPEG Images (QF = 75)	[3]	Our AQTb	Our WQTb
airplane	5969	6483	6385
barbara	5654	6266	6070
boat	5684	6296	6100
fruits	6384	6797	6800
goldhill	5744	6258	6160
lena	6424	7026	6840
peppers	5625	6194	6041
zelda	5918	6619	6334

6. Conclusion

A new method of the reversible data hiding in JPEG image is proposed. We have improved the method in article [7] for JPEG image embedding and proposed the cross-domain using multiple quantization tables for increasing the capacity while remaining the quality of embedding JPEG images. The method is very simple and easy to implement for real applications. The proposed method cannot only be employed on JPEG image, but also JPEG 2000^c images.

The cross-domain frequency is also presented by using the algorithm of JPEG image. According to the algorithm of each digital content such as MPEG4, H.264 and so on, we can define appropriate principle cross-domain frequency.

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^c<https://jpeg.org/jpeg2000/>

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GIẢI PHÁP THUỶ VÂN THUẬN NGHỊCH TRÊN JPEG DỰA TRÊN MIỀN TẦN SỐ KẾT HỢP SỬ DỤNG NHIỀU BẢNG LƯỢNG TỬ HOÁ

Phạm Quang Huy, Tạ Minh Thanh

Tóm tắt

Các kỹ thuật giấu tin thuận nghịch (RDH) cho ảnh JPEG có những thách thức lớn nhằm nâng cao dung lượng, chất lượng và phương pháp nhúng linh hoạt. Trong bài báo này, chúng tôi đề xuất một miền tần số kết hợp mới sử dụng nhiều bảng lượng tử hóa trong thuật toán JPEG. Chúng tôi khảo sát hiệu quả của các hệ số lượng tử hóa trên các bảng DCT để quyết định cách nhúng thông tin thủy vân. So với phương pháp thông thường, kết quả thử nghiệm của chúng tôi cho thấy phương pháp đề xuất có hiệu suất tốt hơn cả về khả năng tăng dung lượng và cải thiện chất lượng ảnh JPEG nhúng sau khi nhúng dữ liệu mật.

Từ khóa

Hệ số DCT, bảng lượng tử hóa, thủy vân thuận nghịch, miền tần số tích hợp, thuật toán JPEG.