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A Lossless Data-hiding Technique based on Wavelet Transform

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Abstract

A lossless data-hiding scheme in this scheme is proposed based on quantized coefficients of discrete wavelet transform (DWT) in the frequency domain. Using the quantized 9/7 wavelet filter, we embed secret data into the successive zero coefficients of the medium-high frequency components in each reconstructed block for 3-level 2D DWT of a cover-image. The procedures of this approach include embedding, extraction, and restoration. Experiment results show that this proposed method can achieve high embedding capacity and acceptable image quality of stego-image, and data reversibility.

1. Introduction

Data hiding results in distortion of the original image. In other words, the original image is not lossless and reversible, resulting in a permanent distortion of the original image, the hidden data, or both. Although some embedding distortion is admissible, for example in military, legal, and medical images, permanent loss of signal fidelity is undesirable. Lossless data embedding, which is also called reversible data embedding, involves embedding invisible data into a digital image. The quality of the image used for embedding should give reasonably high. At the same time, it must be possible to restore the original image exactly after extracting the embedded message. This research focuses on lossless data embedding using a DWT to improve data-hiding capacity and retain good stego-image quality. Many reversible data-hiding techniques have been reported in the literature. These techniques can be classified into two categories: the spatial [1-3] and frequency domain [4-7,9-10].

In the spatial domain, the secret message is inserted directly into the pixels. The most common methods are histogram-based and least-significant bit (LSB) techniques in the spatial domain. Tian [1] presented a high-capacity, low-distortion reversible data-embedding algorithm using difference expansion (DE). The authors explored the potential of redundancies in the digital image to achieve high capacity and to keep distortion low. Ni *et al*. [2] proposed a histogram-based method for data hiding, which used the zero and peak points of an image histogram to embed a message and to recover the original image after extraction of the embedded data.

In the frequency domain, the common well-known methods for data hiding are discrete cosine transform (DCT)-based, discrete wavelet transform (DWT)-based, or based on similar mechanisms. The cover image is first transformed using one of these transformations, and then the secret data are combined with the appropriate coefficients obtained by image transformation to achieve embedding. Fridrich *et al*. [4] proposed the so-called RS scheme, which is a lossless data-embedding method that achieves high capacity by embedding bits of a message into status information on groups of pixels. Chang *et al*. [5] presented a steganographic method in the JPEG domain to embed a secret message into the medium-frequency coefficients of a DCT-transformed cover image. Other than DCT domain schemes, several wavelet techniques that combine histogram- or LSB-based methods to achieve lossless data hiding have been reported [6-7].

In this paper, the aim of our proposed method is to embed secret data into the coefficients after quantizing and rearranged in the quantization factors using 9/7 wavelet filter for a cover image, and to recover the original image.

The reminder of the paper is organized as follows. Section 2 presents the pre-processing for this approach. Section 3 describes the proposed system. Section 4 shows the experimental results. Finally, conclusions give in Section 5.

2. Pre-processing

2.1 2D wavelet transform

Digital wavelet transform (DWT) represents an image as a sum of wavelet functions with different locations and scales [8]. Any decomposition of an image into wavelet involves a pair of waveforms: the high frequencies corresponding to the detailed parts of an image and the low frequencies corresponding to the smooth parts of an image. DWT for an image as a 2D signal can be derived from a 1D DWT.

According to the characteristic of the DW decomposition, an image can be decomposed to four subband images through a 1-level 2-D DWT. These four subband images can be mapped to four subband elements representing LL, HL, LH, and HH, respectively.

2.2 9/7 filter for DWT

The 2-D DWT is mainly composed of the mutilate filters, and because intensive computation is involved in practical applications, such as image compression or edge detection.

The 9/7 filter [9] is commonly regarded to have good performance in image compression applications. The 9/7 filter is so called because its analysis filter has nine nonzero coefficients, while its synthesis filter has seven nonzero coefficients. Except for these values, all the filter coefficients are zeros, and therefore the energy distribution of the 9/7 filter is more concentrated than that of the low frequencies in a DWT. The 9/7 filter can therefore be considered more useful for embedding data into the high-frequency components of the DWT. Hence, in this scheme, this filter is used to decompose the DWT and to compare the results obtained from a DCT-based data-hiding scheme.

2.3 Quantization of DWT coefficients

To obtain a sequence of zero coefficients to improve data-hiding capacity, quantization of a 3-level 2-D DWT for the original image must be performed. Human visual perception is insensitive to high-frequency signals; therefore, it is necessary only to quantize the medium-high frequency coefficients for the HH_1, HL_1, and LH_1 subbands in the 1-level 2-D DWT. The quantized coefficients (Q) corresponding to these three subbands in the DWT can be defined as:

$$Q_{HH_1} = HH_1 \times q_1,\ Q_{HL_1} = HL_1 \times q_2, \\ Q_{LH_1} = LH_1 \times q_3,\ 1 \ge q_2 \ge q_1 \ge 0, \quad (1)$$

where q_1, q_2, and q_3 represent the quantization factors corresponding to HH_1, HL_1, and LH_1 respectively.

To obtain the quantized DWT coefficients, the DCT for the original image is first quantized using the standard quantization table, and then the DWT is quantized using the modified quantization table [10]. Next, the peak signal-to-noise ratio (PSNR) values corresponding to the differences between the quantization tables for the original image and the cover image are computed. Next, assuming that the PSNR values for the DCT-based method and the DWT-based method are the same or similar, a 1-level 2-D DWT for the original image is computed, and the corresponding quantization factors (q_1, q_2, q_3) for the 9/7 filter for the DWT can be estimated using the quantization tables. Table 1 shows the quantization factors for the DWT corresponding to the HH_1, HL_1, and LH_1 and corresponding to the different quantization tables for the DCT.

Table 1 Quantization factors for the 9/7 filter of the DWT using the standard (Std.) and modified (Mod.) quantization tables based on the same PSNR value for the DCT

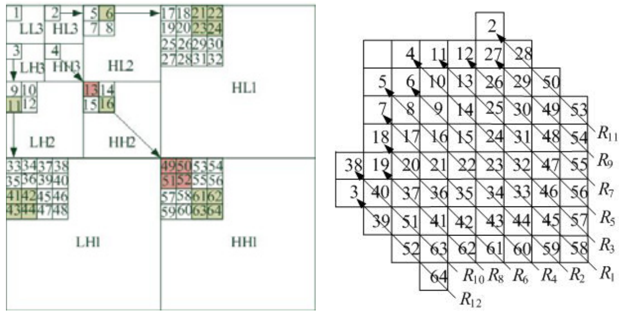
Cover image	$PSNR_1$	q_1		q_2		q_3	
		Std.	Mod	Std.	Mod	Std.	Mod.
Boats	33.98	1/64	1/64	1/2	1/2	1/27	1/22
Mandrill	29.10	1/64	1/64	1/30	1/30	1/9	1/9
Lena	37.34	1/42	1/64	1	1	1/17	1/12

3. Proposed method

The system described here consists of embedding, extraction, and restoration procedures. Some of related procedures are derived from the method of Chang *et al*. [10]. Details of these procedures are described in the following subsections

3.1 Embedding process

This proposed scheme is to hide a secret message generated as a set of binary bits using a pseudo-random number generator, these secret bits use to embed into a cover image. Firstly, we decompose an image into a 3-level 2-D DWT. After decomposing, we can obtain ten subbands, the three subbands for LH_1, HL_1 and HH_1 are quantized used Eq. (1) to obtain the quantization factors given Table 1. Then, all coefficients will be rearranged in a new block derived from [10] and our test, as shown in Fig. 1. Next, the secret data will be embedded into the new block.



(a) (b)

Figure 1. (a) A tree decomposition of a 3-level 2D DWT. (b) A rearranged block.

We define several sets R_i to embed a set of secret bits, as shown in Fig. 2(b). The set $R_i = \left\{ (r_{i,1}, r_{i,2}, \cdots, r_{i,k_i}) \mid 1 \le i \le 12,\ 1 \le k_i \le 7 \right\}$ consists of the quantized DWT coefficients on the line labeled "R_i", which runs from the highest-frequency components to the lowest- frequency components and ensures that there are at least two zero coefficients within this set, where L is the number of bits embedded in a block. Let b_i $(1 \le i \le 12)$ be the length of nonzero values in order from the highest-frequency to the lowest-frequency components in set R_i. This value b_i is an important factor to decide whether the data can hide in R_i or not. If $b_i \ge 2$, the set R_i can hide a secret bit and the embedding position is r_{i,b_i-1}, otherwise, the set R_i cannot hide a secret bit.

First, the value of $z_{i,2}$ is used to indicate the hidden secret bit in set R_i, $(1 \le i \le 12)$ .The embedding are described as follows:

Case 1 : If $b_i < 2$ and if $z_{i,1}$ and $z_{i,2}$ do not exit, there are not secret bits can be hidden in a set R_i.

Although there are not secret bits can be hidden in a set R_i according to Case 1 condition, some ambiguous conditions may happen and cause the receivers to extract a fault secret bit. The possible ambiguous conditions and their corresponding corrective strategies are depicted in the following.

I. Ambiguous conditions and its corrective strategy

If the coefficient sequences in set R_i are given the cases $(x, 0, \cdots, r_{i,k_i})$ or $(0, x, 0, \cdots, r_{i,k_i})$, the values of $r_{i,1}$ and $r_{i,2}$ are changed according to the responding Eqs. (2) and (3) respectively, expressed as follows:

Case I $(x, 0, \cdots, r_{i,k_i})$:

$$r'_{i,1} = \begin{cases} r_{i,1} + 1, & \text{where } r_{i,1} > 0, \\ r_{i,1} - 1, & \text{where } r_{i,1} < 0. \end{cases} \quad (2)$$

Case II $(0, x, 0, \cdots, r_{i,k_i})$:

$$r'_{i,2} = \begin{cases} r_{i,2} + 1, & \text{where } r_{i,2} > 0, \\ r_{i,2} - 1, & \text{where } r_{i,2} < 0. \end{cases} \quad (3)$$

Case 2: If $b_i \geq 2$, the value of $z_{i,2}$ is modified to embed secret bit which is expressed as

$$z_{i,2} = \begin{cases} 0, & \text{when } s_i \text{ is } 0, \\ 1 \text{ or } -1, & \text{when } s_i \text{ is } 1, \end{cases} \quad (4)$$

where 1 or -1 are randomly selected.

According to the previously rules, the secret data can embed into the cover image. However, we need eliminate possibly any ambiguous conditions before hiding data. The ambiguous conditions and the modification strategy are described as follows.

II. Ambiguous condition and its corrective strategy

If the coefficient sequence of set R_i is represented as $(0, 0, \cdots, x, 0)$ and the coefficients of $(r_{i,1}, r_{i,2}, \cdots, r_{i,j-2})$ are zeros, where $x \neq 0,\ 4 \leq j \leq k_i$. According to our definition, $z_{i,2}$ is $r_{i,j-3}$. Suppose that secret bit s_i is 1 and *x* is 1 or -1, it will cause that the receiver may make a false decision when the hidden data extracted from the set R_i. To guarantee that the original coefficients can be restored, it is necessary to detect and modify the ambiguous conditions; the coefficient is changed using Eq. (5), before hiding the secret bit:

$$r'_{i,j-1} = \begin{cases} r_{i,j-1} + 1, & \text{when } r_{i,j-1} > 0, \\ r_{i,j-1} - 1, & \text{when } r_{i,j-1} < 0, \end{cases} \quad (5)$$

where $4 \leq j \leq k_i$.

3.2 Extraction process

The secret data can be extracted from a DWT-based stego-image as follows:

Step 1: Obtain the quantized DWT coefficients from 9/7 of DWT-based stego-image according to our proposed method.

Step 2: Scan each block according to our specified order, such as Fig. 1(b).

Step 3: For each set R_i in a block, let $r_{i,j}$ be a nonzero value for the highest frequency component, where $1 \leq i \leq 12$ and $1 \leq j \leq k_i$.

Step 4: Extract the secret bit s_i that is 0 or 1 from the set R_i, the extraction rules represent as

Rule 1: if $r_{i,j} = 1$ or -1, and $r_{i,j+1} = 0$, then s_i is 1 and sign $r_{i,j}$ as $z_{i,2}$.

Rule 2: if $r_{i,j} = 1$ or -1, and $r_{i,j+1} \neq 0$, $r_{i,j-1} = 0$ and $r_{i,j-2} = 0$, then s_i is 0 and sign $r_{i,j-2}$ as $z_{i,2}$, where $j - 2 \geq 1$.

Rule 3: if $r_{i,j} = 1$ or -1, and $r_{i,j+1} \neq 0,\ j \leq 2$, the s_i does not exist in set R_i.

Rule 4: if $r_{i,j} \neq 1$ or -1, $r_{i,j-1} = 0$ and $r_{i,j-2}$=0, then s_i is 0 and sign $r_{i,j-2}$ as $z_{i,2}$, where $j \geq 3$.

Rule 5: if $r_{i,j} \neq 1$ or -1, and $j \leq 2$, none secret bit in set R_i, that is, s_i does not exist in set R_i.

Rule 6: if $r_{i,j}$ does not exist, then s_i is 0 and sign $r_{i,1}$ as $z_{i,2}$.

Step 5: Repeat Steps 3 and 4 until all blocks are processed.

3.3 Restoring process

After extraction, a restoration procedure must be performed. First, change $z_{i,2}$ in each embeddable set to 0. Then the original value of the modified coefficient in each set is restored as explained below. Let the position of the hidden bit in each embeddable set R_i be $r'_{i,j}$.

Rule 1: If s_i exists and $r'_{i,j+3} = 0$, where $4 \leq (j+3) \leq k_i$, then the original value of $r'_{i,j+2}$ can be restored as:

$$r_{i,j+2} = \begin{cases} r'_{i,j+2} - 1, & \text{if } r'_{i,j+2} > 0, \\ r'_{i,j+2} + 1, & \text{if } r'_{i,j+2} < 0, \end{cases} \quad (6)$$

where $3 \leq (j+2) \leq k_i$.

Rule 2: If s_i does not exist and the two highest-frequency coefficients $\left(r'_{i,1}, r'_{i,2}\right)$ of set R_i are (*x*, 0), where $x \neq 0$, then the original value of $r'_{i,1}$ can be restored as:

$$r_{i,1} = \begin{cases} r'_{i,1} - 1, & \text{if } r'_{i,1} > 0, \\ r'_{i,1} + 1, & \text{if } r'_{i,1} < 0. \end{cases} \tag{7}$$

Rule 3: If s_i does not exist and the three highest-frequency coefficients $\left(r'_{i,1}, r'_{i,2}, r'_{i,3}\right)$ of set R_i are (0, x, 0), where $x \neq 0$, then the original value of $r'_{i,2}$ can be restored as:

$$r_{i,2} = \begin{cases} r'_{i,2} - 1, & \text{if } r'_{i,2} > 0, \\ r'_{i,2} + 1, & \text{if } r'_{i,2} < 0. \end{cases} \tag{8}$$

4. Results

The three gray-level test images with 512×512 pixels are used to as test set. For performance evaluation, the peak-signal-to-noise ratio (PSNR) and mean square error (MSE) are used to evaluate the stego-image quality which are expressed as

$$\text{PSNR} = 10\log_{10}\frac{255^2}{\text{MSE}},\ \text{MSE} = \frac{1}{H \times W}\sum_{i=1}^{H}\sum_{j=1}^{W}\left(\alpha_{ij} - \beta_{ij}\right)^2, \tag{9}$$

where α_{ij} and β_{ij} denote the gray-level values between the cover and stego images; H and W are the height and width of the image, respectively.

Compared with Chang *et al*. [10], we evaluate the stego-image quality based on the same hiding capacity with L=9 in the standard and modified quantization tables in the DCT domain. Table 2 shows the image qualities. In addition, based the same PSNR_1, the hiding capacities compared with the DCT-based method (L=9) with the different tables and the DWT-based method (L=12) with different quantization factors are shown in Table 3. Figures 2-3 show the corresponding stego-images results.

For Tables 2 and 3, it is clear that the results are not only the PSNRs of stego-image but also hiding capacity superior to Chang *et al*. method using the standard or modified quantization tables in DCT.

5. Conclusions

In this paper, we have proposed a lossless data-hiding method based on 9/7 wavelet filter. Using the specified quantization factors for DWT, this approach can hide high capacity and preserve the quality of a stego-image. The results verify that the capacity and visual quality of stego-image are better than Chang *et al*'s method.

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Table 2. PSNRs for stego-images when L=9 for using the standard and modified quantization tables in the DCT.(dB)

Cover image	Std. quantized	9/7 for std.	Modified quantized	9/7 for mod.
Boats	27.49	32.69	29.75	33.99
Mandrill	24.22	30.35	26.46	29.14
Lena	28.13	37.72	30.34	34.14

Table 3. The maximum hiding capacities compared with a DCT based method (L=9) and our method (L=12). (bits)

Cover image	Std. quantized (L=9)	9/7 for std.(L=12)	Modified quantized (L=9)	9/7 for mod. (L=12)
Boats	36817	38948	36710	39151
Mandrill	36094	38847	35402	39394
Lena	36861	39706	36850	39869

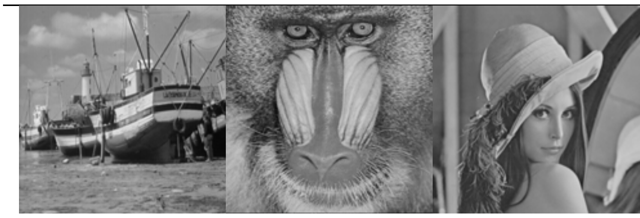

Figure 2.Three stego-images when L=12 for the quantization factors of the 9/7 filter in the DWT using the standard quantization table in the DCT, and the corresponding PSNRs.(a)Boats (28.74dB), (b) Mandrill (28.69 dB), and (c) Lena (29.68 dB).

Figure 3.Three stego-images when L=12 for the quantization factors of the 9/7 filter in the DWT modified quantization table in the DCT, and the corresponding PSNRs.(a)Boats (31.41dB),(b) Mandrill (27.88 dB), and (c) Lena (33.08 dB).