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Reversible Data Hiding Scheme Using Adaptive Block Truncation Coding Based on an Edge-Based Quantization Approach

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Abstract: In this paper, we provide a novel reversible data hiding method using adaptive block truncation coding based on an edge-based quantization (ABTC-EQ) approach. We exploit the characteristic not being used in ABTC-EQ. To accomplish this, we first utilized a Canny edge detector to obtain an edge image and classify each block in a cover image into two versions, edge-block and non-edge-block. Subsequently, k-means clustering was used to obtain three quantization levels and derive the corresponding bit map while the current processing block was the case of an edge-block. Then Zero-Point Fixed Histogram Shifting (ZPF-HS) was applied to embed the secret information into compressed code. The experimental results show that our method provides a high embedding capacity for each test image and performance is better than other methods.

Keywords: BTC; edge-based quantization; reversible data hiding; histogram shifting technique

1. Introduction

Due to the continuing advance of networks in recent years, it has become increasingly convenient and necessary for users to transmit messages to each other through the Internet. This, however, also creates many security problems, including the opportunity for a malicious attacker to destroy the transmitted information or tamper with data due to the openness of the Internet. To address these issues, researchers have explored different approaches, such as conventional cryptographic algorithms and information hiding methods. The former transforms the encrypted message into a meaningless format, but may leave clues for attackers. In contrast, the latter un-perceptively embeds the protected message into cover media. In terms of avoiding attacker attention, the information hiding approach outperforms conventional cryptographic algorithms.

Over the past decade, a variety of information hiding schemes have been proposed [1–19]. These information hiding schemes can be divided into two categories based on the subject that is embedded into a cover media. One is used for secret message transmission [1–4,6,7,10–19] and the other is used for claim of ownership [5,8,9] which is also called watermark scheme. The cover media used to carry a secret message can be image, text, audio or video. Currently, images are the primary media used to conceal secret messages because they can be easily found from the Internet. To embed a secret message into a cover image, there are three alternatives, including: spatial domain [1–4], frequency domain [5–8] and compression domain [9–20]. Spatial domain-based information hiding schemes conceal a secret message into a cover image by simply modifying pixel values of the cover image. A representative

example is Least Significant Bit (LSB) substitution [1]. Frequency domain-based information hiding schemes need to transform a cover image into the frequency domain by using discrete wavelet transform (DWT) [21], discrete cosine transform (DCT) [22], etc. The frequency coefficients are then modified to carry a secret message. For compression domain-based information hiding, a secret message is embedded into the compression codes of a cover image and the compression codes are generated by any kind of compression algorithm, such as VQ [23], SMVQ [24], block truncation coding (BTC) [20] or JPEG. Among the above three types of information hiding schemes, frequency domain methods offer relatively higher protection compared to the others. Based on the reversibility feature of the proposed information hiding schemes, information hiding schemes can be further classified into those that are irreversible [1,2,5,6] and reversible [3,4,7–12,14–20,25–33]. The former can only extract information that is embedded in the media. Decoders still cannot completely restore the original cover image even after the hidden message has been extracted.

For example, in 2004, Chen et al. provided an irreversible scheme that embeds the secret data into a cover image by exploiting the Least Significant Bit (LSB) [1]. Decoders can determine the secret bit according to the LSB value of each pixel. However, decoders cannot recover each pixel back to the original, because this method directly changes the LSB value without recording any information regarding the replaced bits. However, irreversible information hiding schemes are not suitable for concealing a secret message into a cover image that requires exact restoration after data extraction, such as in military or medical applications.

In 1997, Barton [27] first proposed a reversible data hiding method. In this approach, the bits to be overlaid were compressed in advance and added to the bitstring. After that, the bitstring carrying hidden compressed bits was embedded into data block in the cover image. In 2002, Celik et al. [28] presented a method called generalized least significant bit, G-LSB for short, where they utilized a variant of an arithmetic compression algorithm (CALIC) [29] to encode a message and hide the resulting interval number along with extra information that was exploited to recover the cover image. In 2003, Tian [30] proposed a novel reversible information hiding method called difference expansion (DE) by embedding the secret message into the difference values between each pixel pair in a cover image. In 2004, Alattat [31] improved Tian's method by exploiting the difference in expansion of vectors instead of two adjacent pixels to enhance embedding capacity. In 2006, Ni et al. proposed a reversible scheme that hides secret data using histogram shifting [3]. They calculated the frequency of each pixel in the cover image and found zero and peak points to embed the secret data based on the histogram modification. When the receiver extracts the secret message from the cover image, the modified pixel can be recovered back to the original pixel value according to the modified method.

In 2009, Tai et al. [4] designed an efficient extension of the histogram modification technique by constructing a histogram of a cover image based on the differences between pixel values of each pixel pair to enhance the hiding capacity of Ni et al.'s scheme. In 2011, Li et al. [32] proposed a novel reversible watermarking scheme by exploiting prediction-error expansion (PEE), adaptive hiding and pixel selection. Their scheme concentrated on highly relevant regions and pixels of the cover image, and it obtains a high embedding capacity with less distortion. In 2012, in order to provide good visual quality and higher embedding capacity, Chang et al. [33] proposed a reversible data hiding scheme that determines whether a pixel is embeddable or not by calculating the absolute difference of its neighboring pixels. In Chang et al.'s scheme, once the derived absolute difference is larger than the predetermined threshold, the corresponding pixel remains unchanged to maintain a high image quality. However, these methods described above are mainly designed for the spatial domain rather than the compression domain. In general applications, images needed to be compressed before they are transmitted over the Internet because the size of raw images can be large. Since image compression is very popular, it is necessary to design reversible data hiding techniques for the compression domain.

Over the last few years, many hiding schemes designed for the compression domain have been proposed to reduce the transmission size of multimedia files during transmission and to increase the number of alternatives for cover media. Among these methods, many hiding schemes have been

proposed based on block truncation coding (BTC) [14–19], which has been the most efficient and fastest compression method. In 2008, Chang et al. presented an information hiding scheme based on BTC [14]. They applied a genetic algorithm to substitute the original three bitmaps by finding an approximate optimal common bit map. Subsequently, the common bit map and block quantization levels for each block are used to hide the secret information. Side matching and quantization level orders are utilized to make the method reversible. In 2011, Li et al. proposed a reversible data hiding scheme based on BTC [15]. In their scheme, they utilized two quantization levels to generate a histogram. Histogram shifting and bitplane flipping are used to hide the secret data into a compressed code stream to improve the hiding capacity and to retain acceptable image quality. For example, if the secret bit is 1 then the high value and low value will be swapped with each other in the compression code, etc. In 2013, Sun et al. presented a novel BTC-based reversible hiding scheme by adopting a joint neighbor coding technique to embed the secret data into quantization levels [16]. In 2015, Lin et al. also proposed a reversible information hiding method based on BTC. In their scheme, they embed the secret information into the bit map of each image block [19]. However, their method only utilized the concept of BTC, and they did not compress the image so that the stego-image is not the BTC codestream. Although many BTC-based reversible data hiding schemes have been proposed, we found that these schemes are limited by a blocking effect problem. As such, in this paper, we try to propose a BTC-based reversible data hiding scheme without a blocking effect problem. To solve the blocking effect problem while offering a reversibility feature, we utilized Zero-Point Fixed Histogram Shifting (ZPF-HS) to embed the secret information and adaptive block truncation coding based on edge-based quantization (ABTC-EQ) to improve image quality and obtain a high embedding capacity.

The remainder of this paper is divided into five sections. Section 2 introduces the ABTC-EQ method, which forms the basis of our proposed reversible data hiding scheme. Section 3 briefly describes our proposed reversible data hiding scheme. Section 4 presents experiments to prove the performance of the proposed scheme. Finally, conclusions are given in Section 5.

2. Related Work

2.1. Histogram Shifting Technique (HS)

In 2006, Ni et al. presented an information hiding method based on the histogram shifting technique (HS) [3]. HS is a simple and efficient reversible data hiding method. In their scheme, they calculated the frequency of each pixel value in a cover image and generated an image histogram. Some pixel values from the histogram are selected and modified to embed the secret data. The modified pixel values can be recovered when the secret information is extracted, such that reversible data hiding is achieved. Their scheme is described as follows:

Step 1. Input an $H \times W$ sized cover image I .

Step 2. Compute the frequency of each pixel value and construct an image histogram. $Peak$ and $zero$ are the values of peak point and zero point, respectively.

Step 3. Shift the pixel values according to a pair for $peak$ and $zero$. If $peak > zero$, the histogram ranging from $zero + 1$ to $peak - 1$ will be shifted to the left side by decreasing 1. Otherwise, the histogram ranging from $peak + 1$ to $zero - 1$ will be shifted to the right side by adding 1.

$$I'_{row, col} = \begin{cases} I_{row, col} + 1, & \text{if } peak + 1 \leq I_{row, col} \leq zero - 1 \text{ and } peak < zero \\ I_{row, col} - 1, & \text{if } zero + 1 \leq I_{row, col} \leq peak - 1 \text{ and } peak > zero \end{cases} \quad (1)$$

where $I_{row, col}$ and $I'_{row, col}$ are the pixel values at the locations (row, col) of cover image I and modified cover image I' , respectively.

Step 4. Embed the secret information into the modified cover image I' . If the secret bit S is "1" and the pixel value is equal to $peak$, it will be increased or decreased by 1. Otherwise, its value remains unchanged.

$$I''_{row, col} = \begin{cases} I'_{row, col} + 1, & \text{if } I'_{row, col} = peak \text{ and } peak < zero, S = 1 \\ I'_{row, col} - 1, & \text{if } I'_{row, col} = peak \text{ and } peak > zero, S = 1 \\ I'_{row, col}, & \text{if } I'_{row, col} = peak \text{ and } peak < zero, S = 0 \\ I'_{row, col}, & \text{if } I'_{row, col} = peak \text{ and } peak > zero, S = 0 \end{cases} \quad (2)$$

Step 5. Repeat **Step 4** until all $I'_{row, col}$ are processed.

Step 6. Output stego-cover image I'' .

2.2. ABTC-EQ

In 2015, Mathews et al. [23] proposed a novel adaptive block truncation coding technique called ABTC-EQ. It is introduced in detail in this section to offer a better understanding of our proposed method. The cover image is compressed according to the result presented in the edge image that is derived by Canny edge detection [21]. Next, a quantization approach is processed based on the edge information of each block. If a block is determined as non-edge-block, it proceeds with bi-clustering. In contrast, an edge-block proceeds with tri-clustering. All steps are described as follows:

Step 1. Input cover image I sized as $H \times W$ pixels and divide it into $k \times k$ non-overlapping blocks b_i 's, where $i = 0, 1, \dots, \frac{H}{k} \times \frac{W}{k} - 1$ and $k = 4, 8, \dots, 32$.

$$B = \begin{bmatrix} b_0 & \cdots & b_{\frac{H}{k}-1} \\ \vdots & \ddots & \vdots \\ \cdot & \cdots & b_{\frac{H}{k} \times \frac{W}{k} - 1} \end{bmatrix}$$

Step 2. Utilize Canny edge detection to obtain the edge map of the whole cover image denoted as emp .

Canny edge detection is an optimal algorithm including three steps to detect edge information from the given cover image. The first step is to reduce the noise by using Gaussian filter. Next, find the gray levels and apply a non-maximum suppression technique to thin the edge. Then, utilize double thresholds and connectivity analysis to indicate the edge map emp for the given cover image I .

Step 3. Divide the emp into $k \times k$ non-overlapping edge-blocks e_i 's.

$$emp = \begin{bmatrix} e_0 & \cdots & e_{\frac{H}{k}-1} \\ \vdots & \ddots & \vdots \\ \cdot & \cdots & e_{\frac{H}{k} \times \frac{W}{k} - 1} \end{bmatrix}$$

Step 4. Perform block classification based on edge-blocks generated by **Step 3**.

If there is only one edge value, it is 1 in edge-block e_i and the rest of the values are 0, and block b_i can be determined as an edge-block with three quantization levels and goes to **Step 5**. Otherwise, it belongs to the non-edge-block with two quantization levels and goes to **Step 6**.

Step 5. Employ k-means clustering [22] to partition the pixels in the current block b_i into three clusters, C_0, C_1 and C_2 , respectively.

$$C_f = \begin{cases} C_0 = \{x_0^0, x_1^0, \dots, x_r^0\} \\ C_1 = \{x_0^1, x_1^1, \dots, x_r^1\} \\ C_2 = \{x_0^2, x_1^2, \dots, x_r^2\} \end{cases}$$

Then calculate the mean values of each cluster using Equation (3), and these three mean values will serve as three quantization levels.

$$\mu_f = \frac{1}{m_f} \sum_{r=0}^{m_f-1} x_r^f, \quad (3)$$

where $f = 0, 1$ or $2, 0 \leq r \leq k \times k - 1, m_f$ is the member of each cluster and x_r^f 's mean the members in each cluster.

The bp_n^i in BMP^i will be defined according to Equation (4).

$$BMP^i = \begin{bmatrix} bp_0^i & \cdots & bp_{k-1}^i \\ \vdots & \ddots & \vdots \\ \cdot & \cdots & bp_{k \times k - 1}^i \end{bmatrix}, \text{ where } bp_n^i = \begin{cases} 00, & \text{if } x_r^f \in C_0 \\ 01 & \text{if } x_r^f \in C_1 \\ 10 & \text{if } x_r^f \in C_2 \end{cases}, \quad (4)$$

where BMP^i is the bit map of b_i, bp_n^i is the value in BMP^i and $n = 0, 1, \dots, k \times k - 1$.

Step 6. Find the maximum (*max*) and minimum (*min*) values of gray levels in block b_i . Then, compute the average value *avg* of block b_i .

Calculate the value of threshold T using Equation (5).

$$T = \frac{\max + \min + \text{avg}}{3}. \quad (5)$$

Construct the BMP^i by using Equation (6) and calculate the two quantization levels h^i and l^i by using Equations (7) and (8).

$$BMP^i = \begin{bmatrix} bp_0^i & \cdots & bp_{k-1}^i \\ \vdots & \ddots & \vdots \\ \cdot & \cdots & bp_{k \times k - 1}^i \end{bmatrix}, \text{ where } bp_n^i = \begin{cases} 1, & \text{if } p_n^i > T \\ 0, & \text{if } p_n^i \leq T \end{cases} \quad (6)$$

$$h^i = \frac{1}{\text{num}_0} \sum_{r=0}^{\text{num}_0-1} p_n^i, \text{ if } p_n^i > T \quad (7)$$

$$l^i = \frac{1}{\text{num}_1} \sum_{r=0}^{\text{num}_1-1} p_n^i, \text{ if } p_n^i \leq T \quad (8)$$

Here p_n^i is the pixel value in block b_i, num_0 is the number of pixels that are greater than T, num_1 means the numbers that are smaller than or equal to T, h^i is the high value in b_i and l^i is the low value.

Step 7. Repeat **Step 4** to **Step 6** until all block b_i 's are processed and then obtain ABTC-EQ compressed codes.

Figure 1a,b show the encoding flowcharts of BTC [13] and ABTC-EQ [23], respectively. To simplify our example shown in Figure 1, a single block b_i sized 4×4 pixels using BTC and ABTC-EQ, respectively, is demonstrated. We used Equation (9) to calculate the Mean Square Error (*MSE*) of BTC and ABTC-EQ, whose values were 698 and 55, respectively. Obviously, ABTC-EQ has good performance when a block is in the complexity area.

$$MSE = \frac{1}{H \times W} \sum_{row=0}^{H-1} \sum_{col=0}^{W-1} (I'_{row,col} - I_{row,col})^2 \quad (9)$$

where $I'_{row,col}$ and $I_{row,col}$ are the values of the decompressed pixel and the original pixel values.

Original block b_i

108	115	152	187
107	130	178	193
111	147	190	195
121	167	199	190

(a) The flowchart of BTC

Step 1. Calculate the mean value μ and standard deviation σ of block b_i .

$$\mu = 155,$$

$$\text{and } \sigma = 8.62183.$$

Step 2. Compute $high^i$ and low^i

$$high^i = \mu + \sigma \sqrt{\frac{k \times k - q}{q}},$$

$$low^i = \mu - \sigma \sqrt{\frac{q}{k \times k - q}},$$

where q is the number of pixels greater than μ and the values of $high^i$ and low^i are 164 and 146, respectively.

$$\{high^i, low^i\} \longrightarrow high^i || low^i ||$$

Step 3. Construct BMP^i using Eq. (4).

$$BMP^i =$$

0	0	0	1
0	0	1	1
0	0	1	1
0	1	1	1

$$\{high^i, low^i, BMP^i\} \longrightarrow high^i || low^i || BMP^i.$$

Step 4. Output code stream:

Encoding format: $high^i || low^i || BMP^i$
 CS: 10100100||10010010||
 0001001100110111.

(b) The flowchart of ABTC-EQ

Step 1. Utilize Canny edge detector and obtain the edge image emp .

$$emp =$$

0	1	0	0
0	1	0	0
0	1	0	0
1	0	0	0

Step 2. Determine the case of block b_i .

b_i is edge block.

$$\{\text{indicator}\} \longrightarrow 1 ||$$

Step 3. Partition the p_n^i into three cluster using k-means clustering and calculate the mean values of μ_0, μ_1 and μ_2 using Eq. (1).

$$\{00\}C_0 = \{187, 178, 193, 190, 195, 199, 190\}$$

$$\{01\}C_1 = \{152, 147, 167\}$$

$$\{10\}C_2 = \{108, 115, 107, 130, 111, 121\}$$

$$\mu_0 = 190, \mu_1 = 155 \text{ and } \mu_2 = 115$$

$$\{\text{indicator}, \mu_0, \mu_1, \mu_2\} \longrightarrow 1 || \mu_0 || \mu_1 || \mu_2.$$

Step 4. Construct BMP^i using Eq. (2).

$$BMP^i =$$

10	10	01	00
10	10	00	00
10	01	00	00
10	01	00	00

$$\{\text{indicator}, \mu_0, \mu_1, \mu_2, BMP^i\} \longrightarrow$$

Step 5. Output code stream:

Encoding format: $1 || \mu_0 || \mu_1 || \mu_2 || BMP^i$.
 CS: 1||10111110||10011011||01110011||
 10100100101000001001000010010000.

Figure 1. Compression flowcharts of block truncation coding (BTC) and adaptive block truncation coding based on edge-based quantization (ABTC-EQ algorithms): (a) BTC encoding and (b) ABTC-EQ encoding.

3. Proposed Scheme

This section presents the proposed scheme. In our method, we utilized ABTC-EQ to compress the cover image because its reconstructed image quality is relatively good compared to other BTC variant techniques. Next, ZPF-HS was used to embed the secret information into an ABTC-EQ compressed code stream. To further enlarge the hiding capacity of our proposed method, we also embed the secret data into quantization levels. As background for our proposed scheme, Section 3.1 reviews the zero-point fixed histogram shifting (ZPF-HS) that will be used for data embedding in our approach. Our proposed scheme contains two phases: a data embedding phase and the data extraction and recovery phase, which are demonstrated in Sections 3.2 and 3.3, respectively.

3.1. Zero-Point Fixed Histogram Shifting (ZPF-HS)

The histogram shifting technique [3], called HS for short, is a simple and efficient hiding method, and has been widely adopted in various reversible data hiding schemes. In this section, the features of HS are explored and then expanded to support a zero-point fixed scenario as zero-point fixed histogram shifting, called ZPF-HS for short. Finally, ZPF-HS is adopted in our proposed scheme.

In our proposed method, there are only three histogram bins that need to be addressed if the compressed blocks are determined as edge-blocks and the corresponding bit map is the source for our ZPF-HS. Figure 2 shows examples of three possible cases of the bit map for an edge-block. In ABTC-EQ, bits 11 are not being used, as shown in Figure 2. In our scheme, zero point (*zero*) is always set as 11 and the peak point (*peak*) is defined as the bit values in the bit map which has a large population.

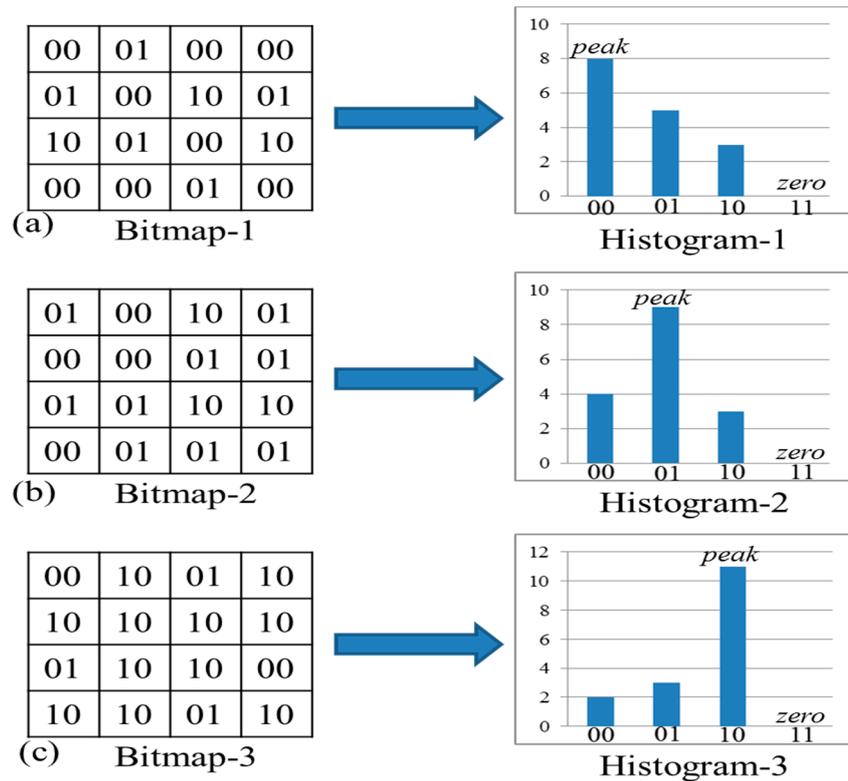


Figure 2. (a–c) are the bit maps and histograms of each case.

Take Figure 2a for example: there are 8 bit values “00”, 5 bit values “01” and 3 bit values “10” in bit map-1. Therefore, peak point is defined as “00”. We exploit the first case shown in Figure 2a as an example to explain in detail our proposed ZPF-HS in Figure 3. Figure 3a shows the original bit map and its corresponding histogram, Figure 3b presents the secret data and Figure 3c is the result of the modified bit map and its corresponding histogram after embedding. In this example, *peak* is defined as “00” and *zero* is defined as “11”, then according to Equation (10) with a zig-zag scan, the secret data can be embedded into the original bit map and the modified bit map is shown in Figure 3c.

$$peak = \begin{cases} peak, & \text{if secret bit is 0} \\ 11, & \text{if secret bit is 1} \end{cases} \quad (10)$$

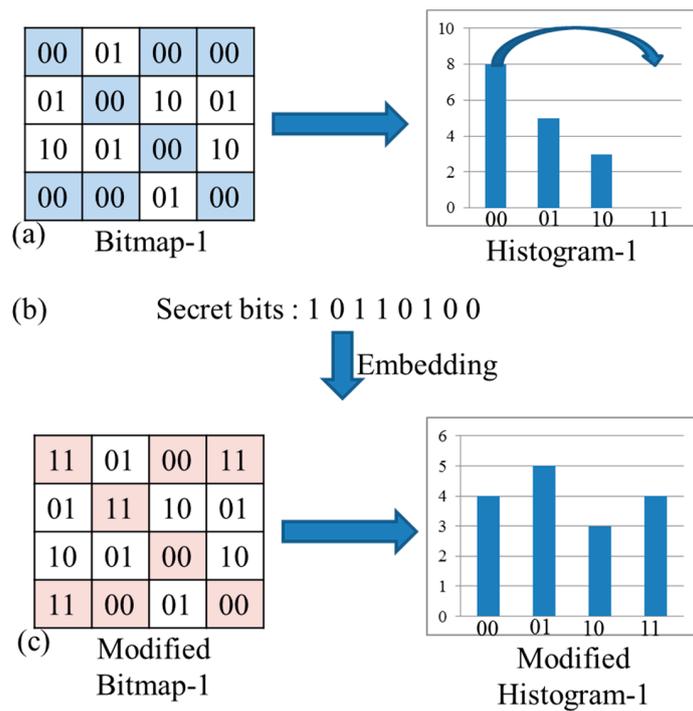


Figure 3. Example of operations in our ZPF-HS. (a) Original bit map and histogram, (b) secret bits and (c) modified bit map and histogram.

3.2. Data Embedding Phase

In our proposed data embedding phase, the embedding operations and encoding phase of ABTC-EQ are merged seamlessly. Blocks are identified as non-edge-block and edge-block after Canny edge detection. Therefore, two block types are identified and two cases of data hiding operations need to be explored in our embedding phases as shown in Figure 4. For an edge-block case, both quantization levels and a bit map are used for data hiding. By contrast, only quantization levels are used for data embedding in a non-edge-block.

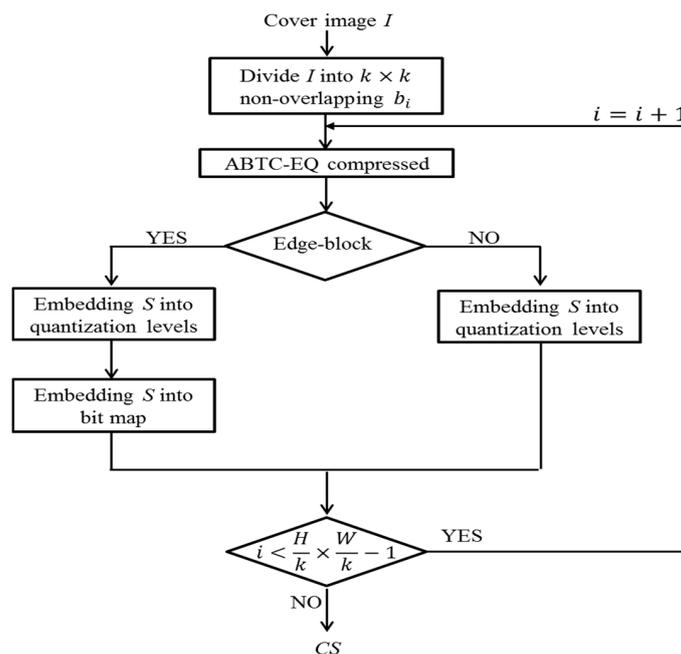


Figure 4. The flowchart of data embedding phase.

In our data embedding phase, the input cover image is sized as $H \times W$ pixels. Each block b_i is sized $k \times k$ pixels, where $i = 0, 1, \dots, \frac{H}{k} \times \frac{W}{k} - 1$. Note that the ABTC-EQ procedure is also included as shown in Figure 4. Secret information S is a bitstream in binary form, and s_l is the value of a secret bit in S , where $s_l = 0$ or 1 and $l = 0, 1, 2, \dots, N$. N is the number of maximum capacity of cover image I . And S is embedded into the ABTC-EQ compressed code stream of cover image I .

Input: Cover image I and secret information S .

Output: Code stream CS .

Step 1. Divide I into $k \times k$ non-overlapping blocks b_i 's.

Step 2. Utilize ABTC-EQ to compress the current processing block b_i .

Step 3. Determine block b_i to be edge-block or non-edge-block. If block b_i is an edge-block, then go to

Step 4. Otherwise, go to **Step 8.**

Step 4. Insert one bit to serve as the indicator and set it as 1. Then, use Equation (3) to compute the mean values μ_0, μ_1 and μ_2 of three clusters C_0, C_1 and C_2 , respectively. Finally, cluster C_{y_1} , which has a large population will be encoded as $1\|\mu_{y_1}\|$, where $\|$ represents the concatenation operation and $y_1 = 0, 1$ or 2 .

Step 5. Read the next s_l from S , if $s_l = 0$, and the remaining clusters will be encoded as $1\|\mu_{y_1}\|\max\{\mu_{f-\{y_1\}}\}\|\min\{\mu_{f-\{y_1\}}\}$, where y_2 and $y_3 \in \{0, 1, 2\}$. Otherwise, encode by $1\|\mu_{y_1}\|\min\{\mu_{f-\{y_1\}}\}\|\max\{\mu_{f-\{y_1\}}\}$.

Step 6. Embed the next s_l from S into the BMP^i and obtain a modified BMP^i by using Equation (10).

Step 7. Output $1\|\mu_{y_1}\|\min\{\mu_{f-\{y_1\}}\}\|\max\{\mu_{f-\{y_1\}}\}\|\text{modified } BMP^i$ to be part of CS .

Step 8. Insert one bit as the indicator and set it as 0. Then, use Equations (7) and (8) to compute two quantization levels h_i and l_i .

Step 9. Determine the next s_l , if the next $s_l = 0$, indicator, h_i and l_i will be encoded by $0\|h_i\|l_i$. Otherwise, it will be encoded by $0\|l_i\|h_i$.

Step 10. Output the indicator, that is the sequence according to the corresponding embedding order of two quantization levels, and the original bit map BMP^i to be part of CS .

Step 11. Repeat **Step 2** to **Step 10** until all blocks b_i 's are processed.

Step 12. Obtain output code stream CS .

We obtain the modified code stream CS , which concealed the S after all the steps are completed. An example of our proposed data embedding phase is shown in Figure 5 to explain each step in detail. Figure 5a shows an example of a 4×4 sized block b_i . Figure 5b presents the histogram of three clusters corresponding bp_n^i in block b_i . Figure 5c,d present the original BMP^i and the modified BMP^i , respectively. Figure 5e provides the code stream of a modified BMP^i . Figure 5f is the sequence of the indicator, three quantization levels and modified BMP^i . Figure 5f presents the binary form of Figure 5g. In Figure 5, all pixels in block b_i will be partitioned into three clusters exploiting k-means clustering. Then, compute the mean values μ_f of three clusters using Equation (3). Because C_0 has the largest population, the C_0 corresponding to bp_n^i is *peak*. The indicator and three quantization levels μ_f 's will be encoded by $1\|\mu_0\|\mu_2\|\mu_1$ while the next s_l is 1. In the next step, construct BMP^i , embed the next s_l into BMP^i using Equation (10) and obtain the modified BMP^i . Finally, we obtain the modified code stream CS .

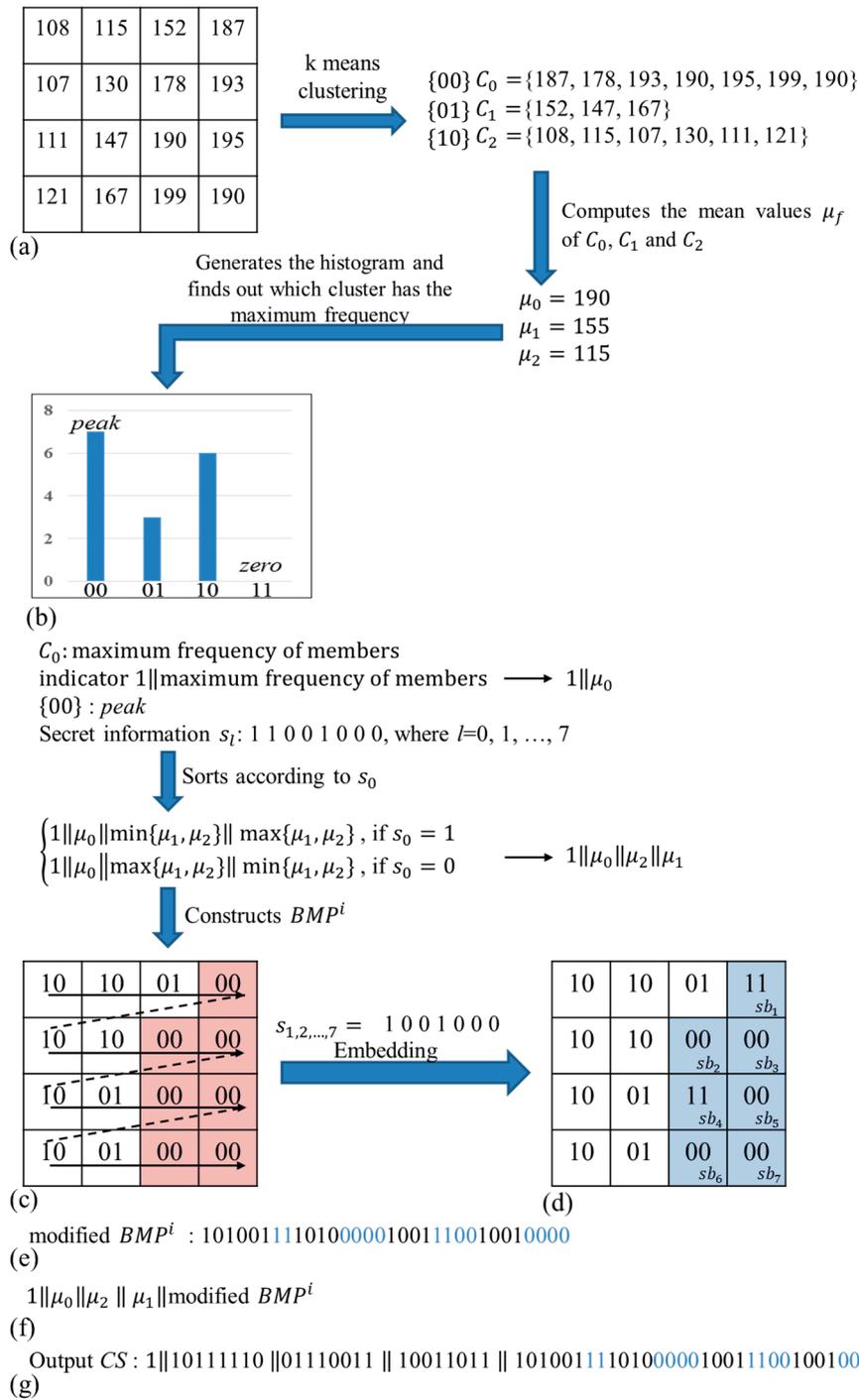


Figure 5. (a) Block b_i sized 4×4 , (b) histogram of block b_i , (c) original BMP^i , (d) modified BMP^i , (e) the code stream of modified BMP^i , (f) structure of code stream CS and (g) output code stream CS.

3.3. Extraction and Recovery Phase

In this section, hidden secret information S is extracted from code stream CS . Because one indicator has been added during our data embedding phase, a decoder can be guided by the indicator to conduct the extraction operation. If the indicator is 1, block b_i will be judged as an edge-block. Three quantization levels will be extracted and among three quantization levels of bp_n^i will serve as the *peak*. In other words, our proposed scheme does not need extra information to record the value of *peak*

to recover the BMP^i , as the histogram shifting technique is adopted in our scheme. Flowchart for extraction and recovery phase is shown in Figure 6.

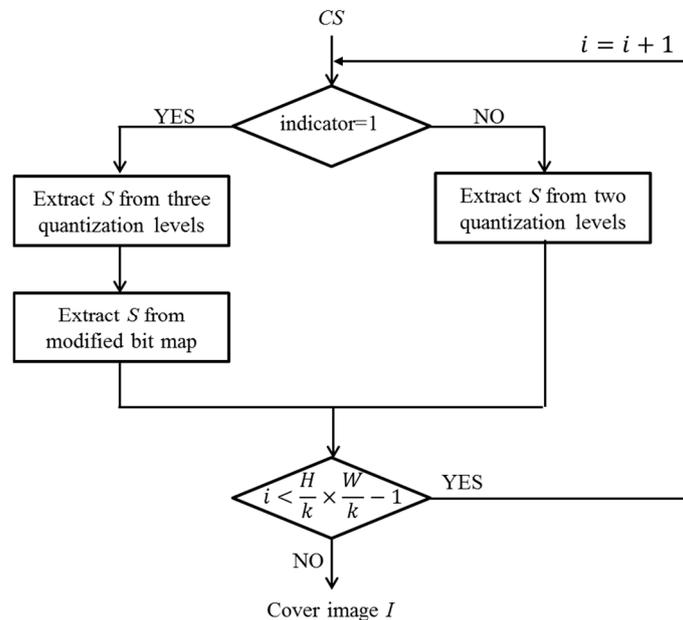


Figure 6. Flowchart for extraction and recovery phase.

Input: Code stream CS .

Output: Cover image I and secret information S .

Step 1. Read the 1-bit indicator in the CS and determine the value of the indicator, if the indicator value is 1, then go to **Step 2**. Otherwise, go to **Step 8**.

Step 2. Read the next 56 bits, then obtain the bit stream of three quantization levels μ'_0 , μ'_1 and μ'_2 , and the modified BMP^i . Its sequence is $1||\mu'_0||\mu'_1||\mu'_2||\text{modified } BMP^i$.

Step 3. Determine the maximum of μ'_1 and μ'_2 . If $\mu'_1 > \mu'_2$, the hidden $s_l = 0$. Otherwise, the hidden $s_l = 1$.

Step 4. Construct the modified BMP^i and sort μ'_0 , μ'_1 and μ'_2 in descending order. The value of $peak$ is μ'_0 's corresponding bp_n^i .

Step 5. Extract the next s_l from the modified BMP^i . If $bp_n^i = peak$, the hidden $s_l = 0$. And if $bp_n^i = 11$, the hidden $s_l = 1$.

Step 6. Modify $zero$ back to $peak$ where $zero = 11$.

Step 7. Decompress block b_i according to each bp_n^i 's corresponding quantization level.

Step 8. Read the next 32 bits, then obtain the bit stream of two quantization levels μ'_0 and μ'_1 , and the original BMP^i . Its sequence is $0||\mu'_0||\mu'_1||\text{original } BMP^i$.

Step 9. Determine the maximum of μ'_0 and μ'_1 . If $\mu'_0 > \mu'_1$, the hidden $s_l = 0$. Otherwise, the hidden $s_l = 1$.

Step 10. Sort μ'_0 and μ'_1 in descending order and decompress block b_i according to each bp_n^i 's corresponding quantization level.

Step 11. Repeat **Steps 1 to 10** until all bits in CS are read and proceeded.

Step 12. Obtain secret information S and decompressed cover image I .

After all steps are completed, decompressed cover image I and secret information S are obtained. We also provide an example to further clarify the extraction and recovery phases, which is shown in Figure 7. Figure 7a shows the CS in binary form, Figure 7b presents the sequence of indicator, three quantization levels and modified BMP^i , Figure 7c shows the modified BMP^i , Figure 7d presents the original BMP^i and Figure 7e provides the extracted S . In Step 1, three quantization levels μ'_0 , μ'_1 and μ'_2

are converted into decimal values. Because $\mu'_1 = 115$ is less than $\mu'_2 = 155$, hidden s_0 is judged as 1. In Step 2, $\mu'_0 = 190$, $\mu'_1 = 115$ and $\mu'_2 = 155$ are sorted in descending order, and μ'_0 corresponding to bp_n^i is peak, so the bp_n^i of peak is determined as 00. As the next step, the modified BMP^i is constructed and $s_{1,2,\dots,7}$ are extracted from a modified BMP^i . If $bp_n^i = peak$, the hidden $s_l = 0$. If $bp_n^i = 11$, the hidden $s_l = 1$. After extracting all S from the modified BMP^i , change all bp_n^i values of 11 into peak. Finally, we can obtain the original BMP^i as shown in Figure 7d.

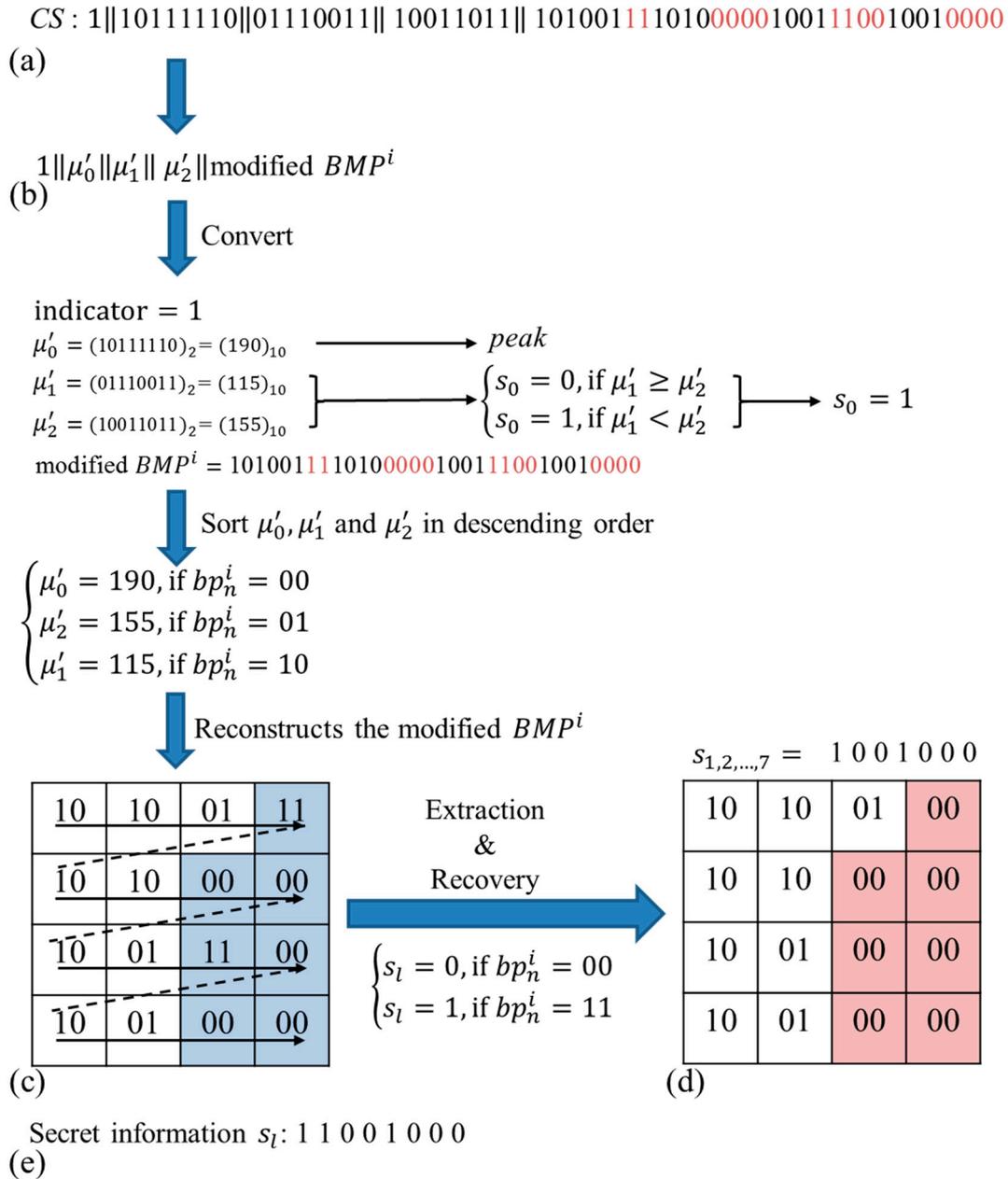


Figure 7. (a) Code stream CS, (b) example of output format, (c) modified BMP^i , (d) recovery BMP^i and (e) secret information S.

4. Experimental Results

We describe some experimental results in this section to demonstrate hiding capacity, output code stream size and the compression ratio in our proposed method. The eleven 512×512 test grayscale cover images as shown in Figure 8 were used for our experiments. The results of their edge images based on Canny edge detection are shown in Figure 9.

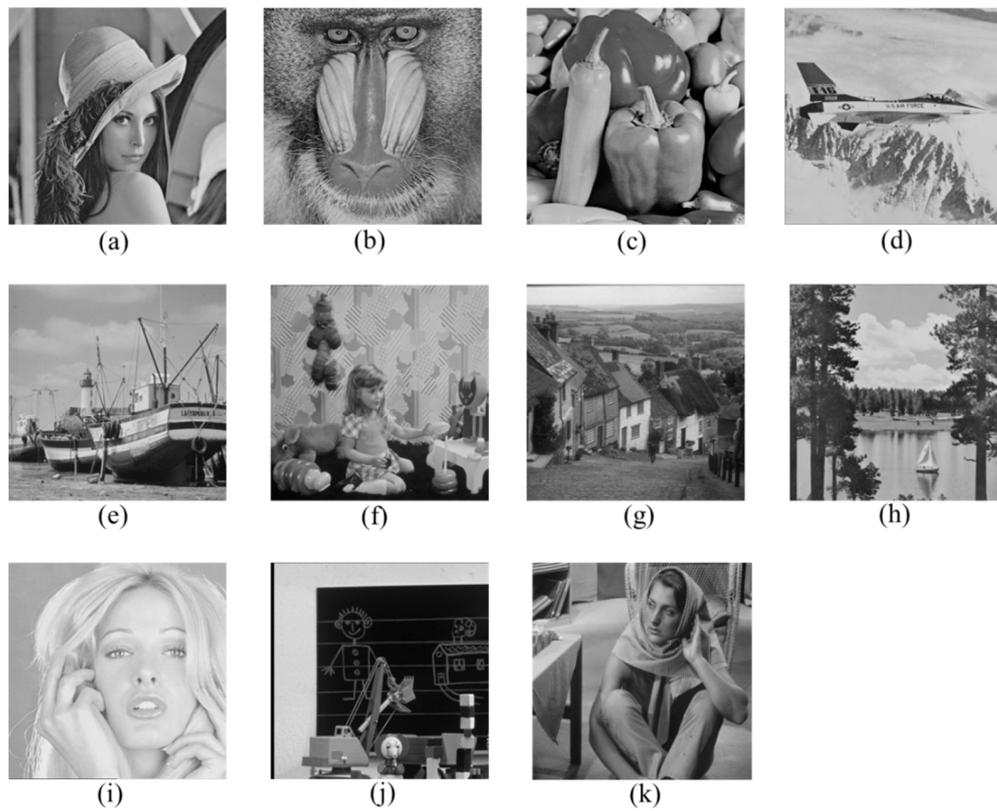


Figure 8. Test images: (a) Lena, (b) Baboon, (c) Peppers, (d) F-16, (e) Fishing Boat, (f) Girl, (g) Gold hill, (h) Sailboat, (i) Tiffany, (j) Toys and (k) Barbara.

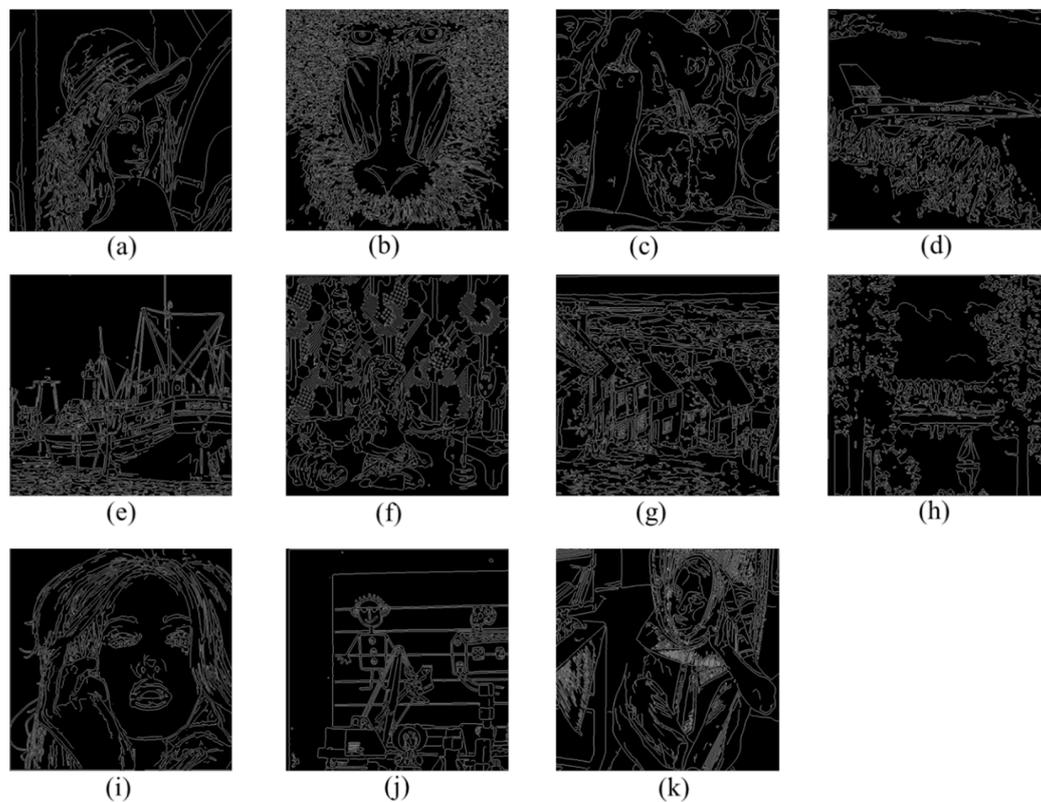


Figure 9. Canny edge detection images of test images: (a) Lena, (b) Baboon, (c) Peppers, (d) F-16, (e) Fishing Boat, (f) Girl, (g) Gold hill, (h) Sailboat, (i) Tiffany, (j) Toys, and (k) Barbara.

To illustrate the performance of our proposed method, the results of our scheme with two different block sizes, 4×4 pixels and 8×8 pixels, are shown in Tables 1 and 2, respectively. In Tables 1 and 2, we present embedding capacity (number of bits), the size of CS (number of bits), compressed ratio (CR) (%) and peak signal-to-noise-ratio (PSNR) (dB) of ABTC-EQ and BTC in two different block sizes, 4×4 pixels and 8×8 pixels, respectively. Obviously, compressing the image to exploit ABTC-EQ can obtain an overall better image quality than BTC, as seen in Tables 1 and 2 by exploiting Equation (12). Because our scheme embeds the secret data into the compression code stream, a decompressed image cannot be directly obtained from the CS that carries the hidden secret data. As for PSNR (dB), it denotes the decompressed image of the recovery CS. The CR of conventional BTC is 0.25 using Equation (11). The size of output CS (number of bits) and PSNR (dB) using ABTC-EQ in the case of an 8×8 block size for b_i is similar to the result of the BTC of the 4×4 block size for b_i . In our scheme, we utilize the characteristic of ABTC-EQ to apply our proposed ZPF-HS to embed the secret data, and we see that the size of CS before and after hiding are the same in our method. Despite the size, our CS (number of bits) is very large because of the cost of bits, while b_i is the edge-block. But the problem of a blocking effect can be better solved with our method than with other compression methods. The average hiding capacity (number of bits) and PSNR (dB) in our experiment are 74,138 (number of bits) and 36.327 (number of bits), respectively. Additionally, the PSNR (dB) means the resulting image after extracting the secret information in Tables 1 and 2.

$$CR = \frac{CS}{H \times W \times n} \quad (11)$$

$$PSNR = 10 \times \log_{10} \left(\frac{255^2}{MSE} \right). \quad (12)$$

Table 1. Performance of our proposed method in 4×4 block sizes for each block b_i .

Image with Block Size 4×4	Capacity (Number of Bits)	CS (Number of Bits)	CR (%)	ABTC-EQ PSNR (dB)	BTC PSNR (dB)
Lena	63,342	675,384	0.3220	37.115	33.659
Baboon	102,999	796,152	0.3796	31.255	27.752
Peppers	63,603	670,944	0.3199	37.486	34.151
F-16	66,094	675,240	0.3220	37.405	33.359
Fishing boat	70,813	695,712	0.3317	35.944	32.000
Girl	88,051	739,800	0.3528	38.157	34.706
Gold hill	89,745	751,176	0.3582	37.075	33.659
Sailboat	69,283	689,736	0.3289	34.653	31.139
Tiffany	72,395	691,536	0.3298	40.153	36.991
Toys	56,115	650,696	0.3103	37.666	33.216
Barbara	73,083	710,496	0.3388	32.688	29.868
Average	74,138	704,261	0.3358	36.327	32.773

From Table 1, we can see that the average capacity is around 74,000 bits and the CR is about 0.3358% when the block size is 4×4 pixels.

Table 2. Performance of our proposed method in 8×8 block sizes for each block b_i .

Image with Block Size 8×8	Capacity (Number of Bits)	CS (Number of Bits)	CR (%)	ABTC-EQ PSNR (dB)	BTC PSNR (dB)
Lena	76,671	480,096	0.2289	33.892	30.273
Baboon	110,340	565,488	0.2696	29.025	25.843
Peppers	83,774	486,792	0.2321	33.995	30.273
F-16	80,009	474,264	0.2261	34.276	30.204
Fishing boat	84,791	489,960	0.2336	32.821	29.042
Girl	108,217	544,104	0.2594	34.934	31.055

Table 2. Cont.

Image with Block Size 8×8	Capacity (Number of Bits)	CS (Number of Bits)	CR (%)	ABTC-EQ PSNR (dB)	BTC PSNR (dB)
Gold hill	114,533	559,440	0.2668	33.859	30.723
Sailboat	87,997	495,432	0.2362	31.887	28.129
Tiffany	90,900	497,088	0.2370	37.239	33.979
Toys	70,889	455,112	0.2170	34.198	30.069
Barbara	87,264	510,048	0.2432	30.917	27.832
Average	90,489	505,257	0.2409	33.368	29.766

In comparison, we can see that the average capacity is up to 90,000 bits and the CR is about 0.2409% when the block size is changed to 8×8 pixels as shown in Table 2. Certainly, the average image quality will be slightly decreased to 33.368 dB, but it is significantly higher than the average PSNR offered by conventional BTC.

To demonstrate the performance results for our proposed scheme, the proposed method in this experiment was compared to previous schemes, i.e., Chang et al. [14], Li et al. [15], Sun et al. [16] and Lin et al. [19] in terms of embedding capacity (number of bits) and embedding efficiency (EF) (%), the results of which are shown in Table 3. These four existing schemes are selected and compared with our proposed scheme because they are reversible data hiding schemes and they are either designed for BTC or AMBTC. Moreover, their hiding strategies are embedding secrets into bitmap and two quantization levels, which are the same as ours. Here, EF was used to evaluate embedding efficiency, which is defined as follows:

$$EF = \frac{\text{Capacity}}{\|CS\|}, \quad (13)$$

where $\|CS\|$ is the size of the output CS and Capacity is the embedding capacity of each test image.

Table 3. Embedding capacity (number of bits) and EF (%) for the proposed scheme and four previous schemes.

Schemes	Parameters	Lena	F-16	Sailboat	Girl	Toys	Barbara
Chang et al. [14]	Capacity	31,011	30,518	28,766	30,962	27,870	30,151
	CS	524,288	524,288	524,288	524,288	524,288	524,288
	EF	0.0591	0.0582	0.0549	0.0591	0.0532	0.0575
Li et al. [15]	Capacity	16,789	17,659	17,082	16,990	17,761	16,755
	CS	524,288	524,288	524,288	524,288	524,288	524,288
	EF	0.032	0.0337	0.0326	0.0324	0.0339	0.032
Sun et al. [16]	Capacity	64,008	64,008	64,008	64,008	64,008	64,008
	CS	524,288	524,288	524,288	524,288	524,288	524,288
	EF	0.1221	0.1221	0.1221	0.1221	0.1221	0.1221
Lin et al. [19]	Capacity	262,112	261,984	262,096	262,128	262,112	262,128
	CS	2,097,152	2,097,152	2,097,152	2,097,152	2,097,152	2,097,152
	EF	0.125	0.1249	0.125	0.125	0.125	0.125
Our scheme	Capacity	76,671	80,009	84,791	108,217	70,889	87,264
	CS	480,096	474,264	495,432	544,104	455,112	510,048
	EF	0.1597	0.1687	0.1731	0.1989	0.1558	0.1711

In this experiment, the size of all test images were 512×512 pixels and the block size was set as 8×8 pixels. In this experiment, our embedding capacity was better than three previous schemes [14,16,17]. While Lin et al.'s scheme provides good hiding capacity performance, their scheme extracts the secret data from the 512×512 resulting images instead of extracting the secret information from the output CS (number of bits). Therefore, the size of each CS (number of bits) in Lin et al.'s scheme is $512 \times 512 \times 8$. The size of our CS (number of bits) remains unchanged even after embedding the secret information. In our scheme, the sizes of CS's for, "Lena," "F-16," "Sailboat," "Girl," "Toys"

and “Barbara” are 480,096 (number of bits); 474,264 (number of bits); 495,432 (number of bits); 544,104 (number of bits); 455,112 (number of bits) and 510,048 (number of bits), respectively, and are shown in Table 3. For the purpose of having a better comparison with the previous four methods, we utilize EF (%) to analyze the performance of our scheme and compare to other schemes using Equation (13). Our proposed scheme obtained a higher EF than the previous four methods. Moreover, the EF offered by Lin et al.’s scheme is lower than ours because their results are presented as images rather than from the code stream.

5. Conclusions

This paper presented a novel reversible data hiding method using block truncation coding based on an edge-based quantization approach. By applying two embedding levels and our proposed ZPF-HS to hide the secret information, it was possible to have a high capacity, high $PSNR$ and high EF despite the generation of a large CS size. In addition, we utilized n bits after the indicator to record the *peak* while blocks are edge-block to ensure that our method exactly restores the original cover image. The experimental results show that our proposed method is indeed suitable for hiding large volumes of information in multimedia. However, it still remains that one value 11 of bitmap cannot be used in the ABTC-EQ compressed method. Our future work will concentrate on how to utilize this value that is not being used in ABTC-EQ to enhance image quality and how to exploit this feature to embed more secret information into compressed code. Moreover, two possible approaches, i.e., CNN and hyperchaos, will be explored and applied when we try to study the above two objectives.

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