An Adaptive Reversible Data Hiding Scheme for JPEG Images

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Abstract. Currently JPEG is the most popular image file format and the majority of images are stored in JPEG format due to storage constraint. Recently, reversible data hiding (RDH) for JPEG images draws researchers attention and has been developed rapidly. Due to the compression, performing RDH on a typical JPEG image is much more difficult than that on an uncompressed image. In this paper, we propose an adaptive reversible data hiding method for JPEG images, which is based on histogram shifting. We propose to select the optimal expandable bins-pair at image level by adopting a k-th nearest neighbors (KNN) algorithm. By developing a new block selection strategy, we can adaptively select the to-be-embedded blocks. Then, the message bits are embedded into the selected blocks at a specific bins-pair via the histogram shifting algorithm. Experimental results demonstrate that our proposed method can achieve a higher image quality and a less increased file size compared to the current state-of-the-art RDH method for JPEG images.

Keywords: Reversible data hiding · JPEG image · KNN · Histogram shifting

1 Introduction

In the past two decades, digital image data embedding technologies, which usually embed a data stream into image(s), has been developed rapidly due to the large demand of image data embedding applications. According to different application scenes, it evolves many technologies. For example, steganography [11] technology is applied to secret communication, and watermarking [13] is used in authentication, broadcast, copyright protection and copy control. However, both kind of methods did not consider to restore the original cover object. In reality, some special areas such as medical, art, military and etc., usually value data integrity and cannot tolerate any extra modifications on the original data. Under these circumstances, reversible data hiding (RDH) has been developed

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for hiding data into a cover object, such that the hidden information can be extracted and the original cover object can also be reconstructed.

Ordinary RDH algorithms, such as histogram shifting [9], difference expansion [6,14], pixel groups' geometric structure [18], DNA XNOR [15] etc., are usually applied to uncompressed images. However, due to the characteristics of compression, most of the ordinary RDH methods cannot be directly applied to compressed images such as JPEG [16] images. Therefore, RDH for compressed images demands a special design. In this paper, we focus on the RDH schemes for JPEG images. As it summarized in [5], designing a RDH method for JPEG images usually have three difficulties. Firstly, the redundancies, which is usually being utilized by the RDH method to achieve embedding, in JPEG images are usually less than uncompressed images. Secondly, the JPEG quantization process usually prevent RDH methods to embed before quantization while the embedding after quantization may introduces large distortions. Thirdly, since JPEG images usually have small file size, which is also the advantage of compressed images, the file size increasement after embedding should be constrained to be small.

Despite the difficulties when designing the RDH schemes for JPEG images, recently, RDH for JPEG images has been developed rapidly by many researchers due to the popularity of JPEG file format. [3] compresses the sequence of LSB values of the cover image coefficients, such that the watermark can be embedded into the empty space. Unfortunately, this method has low embedding capacity and large increasement of the file size. [17] manipulates the content of the quantization table such that the LSBs of the newly quantized coefficients at some locations, which corresponds to the manipulated locations in the quantization table, can load the secret message. Experimental results of this method indicate that it owns a large embedding capacity and a good image quality of the embedded image accompanied by a large increasement of file size. The methods in [8] and [4] embed information by modifying the Huffman table, which yields a good embedded image quality but a small embedding capacity. In [10], Nikoladis et al. propose a different method which modifies the zero value coefficients behind the last non-zero coefficient of each block, and achieves an excellent performance in terms of the visual quality which fails in preserving the file size.

Besides of the above mentioned methods, recently, the histogram shifting (HS) based RDH methods has been developed quickly for JPEG images. In Xuan et al.'s paper [19], a RDH method, the which only gives limited performance, has been proposed by simply applying the HS algorithm to the quantized DCT coefficients. Sakai et al. in [12] improved Xuan et al.'s method by an adaptive embedding method. It chooses smooth region of the image to embed message, and gives superior performance compared to Xuan et al.'s method. In [7], the proposed method selects the JPEG coefficients at certain frequencies, and only embeds the data at these selected coefficients by a HS algorithm. Recently, Huang et al. in [5] also proposed a HS based RDH method for JPEG images by selecting the to-be-embedded blocks adaptively according to the number of zero AC coefficients of the block. Only AC coefficients whose value is 1 or -1 are expanded to carry message bits. Although this method introduces the current state-of-the-art performance, the embedding bins-pair $(-1, 1)$ may not be optimal for different image contents and embedding messages. Both of the visual quality and image's file size it achieves advantage than the formal level of this kind method.

To inherent the strength of HS based RDH method for JPEG images while further improve the performance, in this paper, we propose a new reversible data hiding method, RDH for JPEG image via Adaptive Bins-pair and Block Selection (ABBS), for JPEG images based on Huang et al.'s method [5]. To achieve a higher payload and protect the marked JPEG image's quality. The proposed method propose an algorithm to adaptively select the optimal expandable bins-pair for each cover image by adopting a KNN algorithm. Then ABBS chooses the to-be-embedded blocks via a new block selection strategy. With the embedding blocks and bins-pair selected, the embedding can be achieved. Experiments demonstrate that the proposed method achieves better performance compared to the current state-of-the-art Huang et al.'s method.

The rest of the paper is organized as follows. In Sect. 2, backgrounds of JPEG compression and Huang et al.'s method are introduced. Section 3 describes the proposed method. Section 4 presents the experimental results. The conclusion is drawn in Sect. 5.

2 Backgrounds

In this section, a brief introduction of JPEG compression is given. Then, an interpretation of Huang et al. [5]'s method is explained.

2.1 JPEG Compression

JPEG compression is a common lossy compression standard for digital images. As a parameter of JPEG compression process, the quality factor (QF) corresponds to the compression ratio and image quality after the compression, QF is from 1 to 100 (100 is near lossless).

Figure 1 shows the main procedures of JPEG compression. The system firstly divides the raw image into the non-overlapped 8×8 blocks. Then, DCT (Discrete Cosine Transform) is applied to each block. According to the JPEG quality factor, a corresponding quantization table is selected and the DCT transformed blocks are quantized accordingly. Figure 2 shows an example of a quantization table for $QF = 50$. After quantization, the quantized coefficients will be pre-compressed. The direct current (DC) coefficients will be encoded by the differential pulse code modulation (DPCM), while the alternating current (AC) coefficients will be arranged in a zigzag order and encoded with the run length encoding (RLE). Finally, Huffman coding is applied to the symbol string. A complete JPEG compression file is consist of the head information and the encoded data.

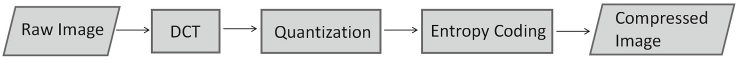

Fig. 1. JPEG compression process.

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

Fig. 2. Quantization table (QF = 50).

2.2 RDH Method in [5]

As we mentioned in Sect. 1, Huang et al. [5] proposed a HS based RDH method for JPEG images. The procedures of Huang et al.'s method is given in Fig. 3. The method generates a histogram of quantized DCT coefficients firstly. Then they perform a block selection strategy which can adaptively choose the to-be-embedded blocks. At last, the bins-pair $(-1,\ 1)$ of the selected blocks are expanded for embedding the message bits. However, the method only exploits the $(-1,\ 1)$ pair as the expandable bins-pair for every image. Without considering the different features of different images, employing a fixed bins-pair for all images might not be the best approach. For example, when the cover image contains many quantized DCT coefficients whose absolute value is larger than 1 and the to-be-embedded message length is relatively short, the $(-1,\ 1)$ may not be the best expandable bins-pair, because more coefficients may be changed in the progress of the histogram shifting embedding at $(-1,\ 1)$. This may introduce more distortions than employing other bins-pair. Thus, we proposes an adaptively bins-pair selection method which is explained in next section.

3 Proposed Method

In this section, we present our method, RDH for JPEG image via Adaptive Bins-pair and Block Selection (ABBS) in details. At first, a histogram of the quantized DCT coefficients is generated and the expandable bins-pair is calculated. Then ABBS chooses a set of blocks from the cover image. Only these blocks will be embedded. At last, we embed the message bits in the bins-pair of the selected

The steps of the embedding :
- generate histogram about the JPEG coefficients of the image, set the (-1,1) as the bins-pair which used to hide message bits;
- Let ***t*** be the number of zero JPEG coefficients of a block. Find the biggest ***t*** so that the embedding capacity of those blocks ,that have a zero JPEG coefficients no more than ***t***, is more than serect message length. Note the biggest ***t*** as ***Tz*** ;
- visit every blocks . If its ***t*** is small than ***Tz*** then skip, else use histogram-shifting method to expand the 1 or -1 coefficient to embed message bits.

The steps of the extraction:
- get the information of ***Tz***;
- visit every blocks. If its ***t*** is small than ***Tz*** then skip, else extact data and backfill the bins with value 1 and -1.

Fig. 3. Summary of Huang et al.'s method.

blocks. Therefore, in this section, we first introduce our expandable bins-pair and block selection strategy and then summarize the framework.

Note that, in this method, we only consider amending the AC coefficients, because DC coefficients can only offer a small embedding capacity while introduce large distortions. As mentioned in Sect. 2.1, the AC coefficients are encoded with RLE. Since changing the coefficients after the position of last nonzero coefficients, may significantly increases the JPEG file size and introduces large distortion, the proposed method only considers to amend the AC coefficients on and before the position of last nonzero coefficients. For simplicity, the DCT coefficients in the following sections represents the AC coefficients on and before the position of last nonzero coefficients.

3.1 Expandable Bins-Pair in Histogram and Block Selection

Huang et al.'s method exploits $(-1,1)$ as the expandable bins-pair, which is not an adaptive pattern, and there often exists other bins-pair which gives better performance. According to the HS mechanism, the expandable bins-pair directly corresponds to the embedded image quality and the increased file size. Thus it is important to select a good bins-pair for each image. ABBS proposes to find the different bins-pairs for different images by adopting a KNN (k-nearest neighbors) algorithm [1]. The embedding block selection method is also different from the Huang et al.'s.

KNN for Choosing Bins-Pair. Since different bins-pair results different modified histogram, a good bins-pair must satisfies certain criteria. Firstly, the bins-pair can offer enough payload. Secondly, the embedding distortions is low. Thirdly, the file size is preserved.

With the three criteria, we can try to find the optimal bins-pair for any histogram. Here, the histogram is derived from the quantized DCT coefficients. As we mentioned in Sect. 2.1, changing the quantized DCT coefficients will affect the file size and image's visual quality. In our method, we adopts the KNN algorithm to find the optimal bins-pair from the quantized DCT coefficients histogram.

We first prepare an image database and find the optimal bins-pair of each image according the three criteria. In this case, the bins-pair is the class label, images which own identical bins-pairs are in the same class. Then we extract features of each image. These features and corresponding labels serve as training set.

The key point is feature. To better illustrate the feature, suppose an image named $I(512 \times 512)$ is going to be processed. We firstly transform I to $I^{'}(64 \times 4096)$. Each column of $I^{'}$ is a block of I with the zigzag scanning order. Discard the first row of $I^{'}$ to get I_a because DC coefficients are unchanged in our method. Then the algorithm calculates the threshold M, where the histogram of first M rows of I_a can support at least one bins-pair. Let S_M be the set consists of all the elements in the first M rows of I_a. We denote $(x_1, x_2, ..., x_n)$ as a feature of I.

$$x_i = \frac{h(i)}{messagelength}, 1 \leq i \leq n. \tag{1}$$

where $h(1)$ is the number of $0s$ in S_M, $h(2)$ is the number of $1s$ in S_M, $h(3)$ is the number of $-1s$ in S_M, $h(4)$ is the number of $2s$ in S_M, $h(5)$ is the number of $-2s$ in S_M, etc.

After collecting the features and optimal bins-pairs of the images, the training set is constructed. Note that the paper adopt Euclidean distance to calculate the distance between two features.

After the training is finished, the optimal bins-pair selection can be performed as follow. Given an image which is going to be embedded, we extract its feature. Then we search for the nearest k neighbors of the feature in the training set. The most common label of the k neighbors is the current optimal label for this to-be-embedded image. As we explained above, the label represent optimal bins-pair.

According to the quantization tables in JPEG compression (for example as Fig. 2), lower frequency components are usually being quantized with smaller quantization step than the high frequency components. This indicates that the modifications on low frequency components are usually smaller than modifying the high frequency components. Then, if the quantized coefficients must be amended for embedding, it will cause less image quality distortions to change the low frequency values. Thus we only consider first M rows of I_a.

In our experiments, the dimension of the feature n is set to be 17, because the dimension of the features must be fixed for latter distance calculations and fact is that there only exist a few candidate bins-pair which possesses the potential to be the optimal bins-pair. As the empirical results in Fig. 4 indicate, most coefficients usually contributes little.

Figure 4 includes four histograms of quantized DCT coefficient at four QF levels. The coefficients are from S_M where $M = 10$. As we can observe, the bins which are far away from the peak bin usually gives near zero count number, thus they can only provide a near zero embedding capacity. Moreover, these

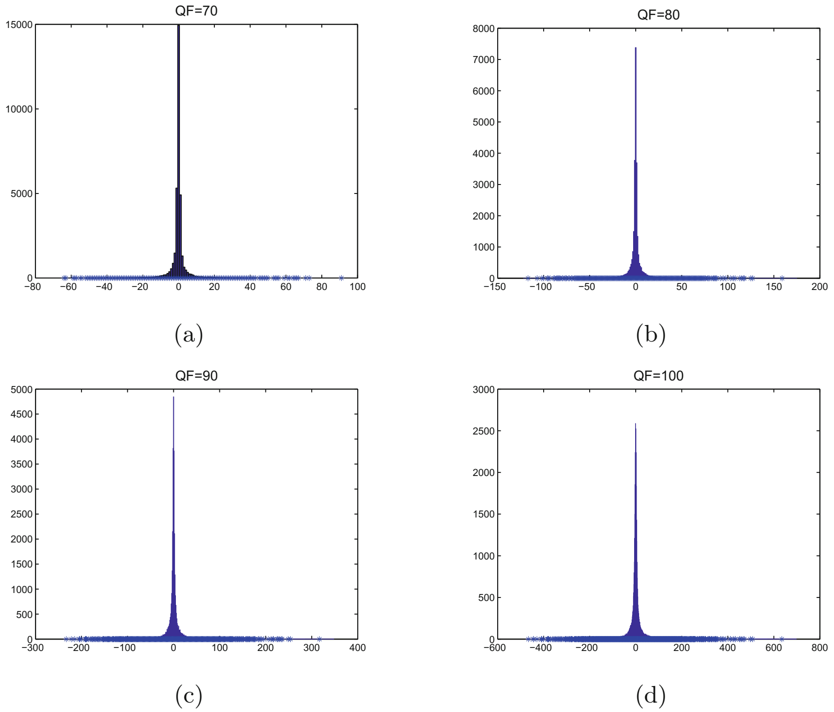

Fig. 4. Histogram of quantized DCT coefficients of S_{10} from lena.jpg: (a) QF = 70, (b) QF = 80, (c) QF = 90, (d) QF = 100.

coefficients are more likely to be in the high frequency locations. Therefore, in general, these bins have a very small possibility to be the optimal bins-pair.

Block Selection Strategy. Since the proposed method only modifies the AC coefficients on and before the position of the last nonzero coefficient, we denote these coefficients as changeable-coefficients. Unfortunately, not all the blocks are suitable for HS embedding. The blocks with lots of changeable-coefficients will introduce more distortions than others when performing the embedding. Hence, those blocks are unappropriate to embed the information. ABBS selects suitable blocks for carrying out embedding. The details are explained as following.

Blocks with different number of changeable-coefficients own different characteristics. The Empirical results indicate that in the low frequency part, the coefficients of block with a large number of changeable-coefficients are usually more divergent than that of the blocks with a small number of changeable-coefficients.

Figure 5 employs the test image Baboon and different JPEG quality factors. The horizontal axis represents 63 block sets, each of which contains a corresponding number of changeable-coefficients. For example, 1 in the horizontal axis represent the block set which consists of blocks only have one changeable-coefficients.

The vertical axis shows the entropy of different sets (in their low frequency part). Similarly, Fig. 6 employs the test image Lena and different JPEG quality factors.

According to the Figs. 5 and 6, the blocks which contains less coefficients own a smaller entropy, i.e., those blocks with less changeable-coefficients will have a smaller entropy.

Since when a data set has a higher entropy, the histogram will be more flat and vice versa, and a flat histogram yields more distortions during the embedding, in the proposed method, only the blocks with small number of changeable-coefficients are select to embed the message bits. We search for the threshold C, select those blocks, whose number of changeable-coefficients is smaller than C, to form a block set S_C. C should satisfy a condition that S_C can offer enough payload. After C is calculated, only the block in S_C will be embedded.

3.2 Embedding Procedure of ABBS

The embedding procedure can be summarized as follows.

- **step 1:** Calculate the optimal bins-pair $(bin1, bin2)$.
- **step 2:** Calculate the threshold C.
- **step 3:** Generate a block set S_C according to C.

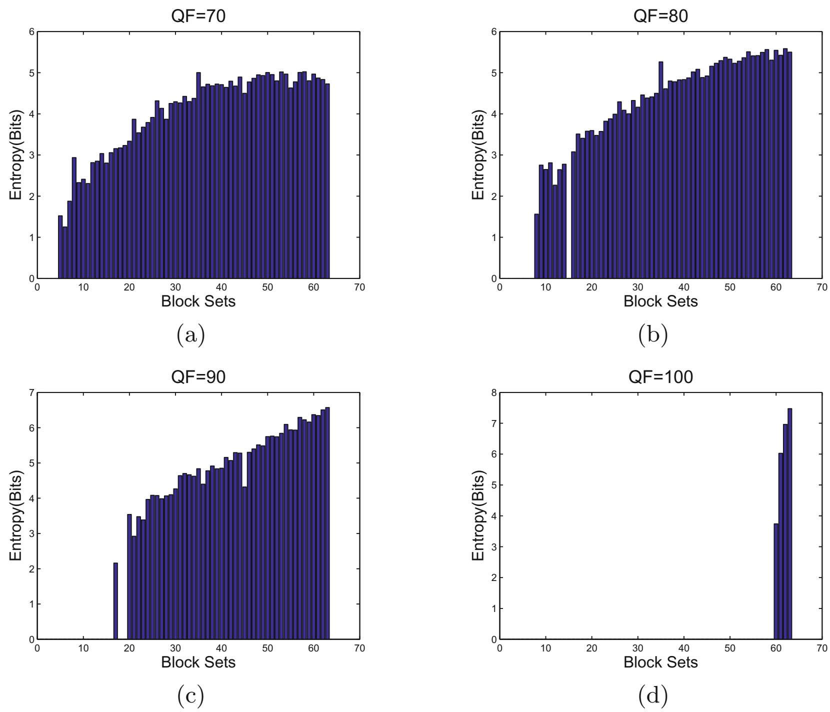

Fig. 5. Statistic Entropy Information of the image Baboon at different QF levels.

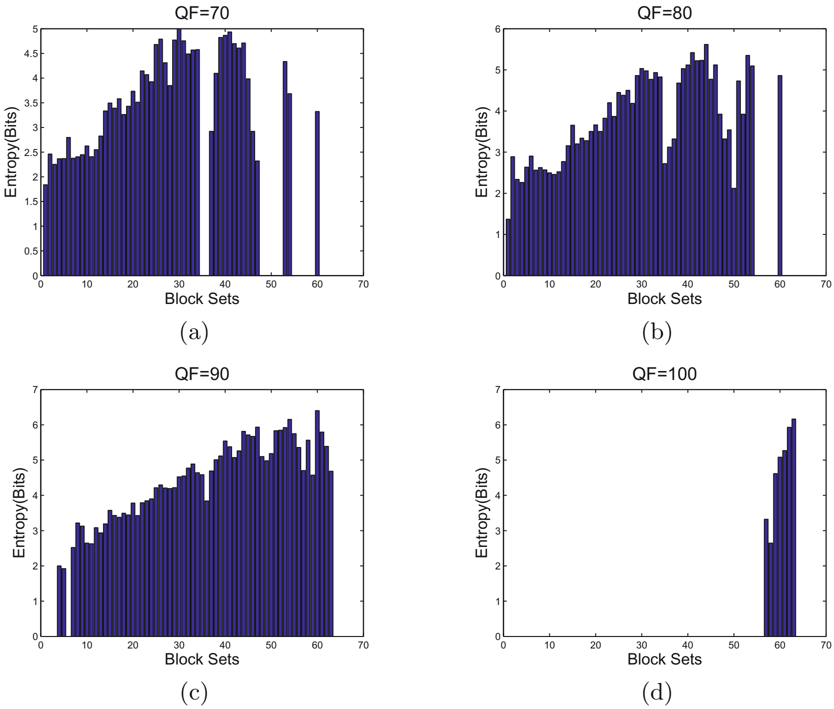

Fig. 6. Statistic Entropy Information of the image Lena at different QF levels.

– **step 4:** Histogram shifting in S_C according to message bits.
– **step 5:** Add the side information$((bin1, bin2), C)$ into the image.

Suppose a message with M bits is required to be embedded into an image I. The feature f will firstly be extracted. The optimal bins-pair $(bin1, bin2)$ can be obtained via the proposed bins-pair selection approach. Then, according to the $(bin1, bin2)$ and embedding capacity, ABBS calculates the C, and thus obtain the embedding block set. S_C, in which each block possesses a number of changeable-coefficients smaller than C. Note that C must satisfy that S_C provides enough capacity to embed M bits. Then, ABBS embeds data in the blocks belongs to S_C as Eqs. 2 and 3.

$$\widetilde{X_i} = \begin{cases} X_i + sign(X_i) * m & X_i = bin1 \,\text{or}\, X_i = bin2, \\ X_i + sign(X_i) & X_i < bin1 \,\text{or}\, X_i > bin2. \end{cases} \tag{2}$$

$$sign(x) = \begin{cases} 1 & x > 0, \\ 0 & x = 0, \\ -1 & x < 0. \end{cases} \tag{3}$$

In the Eq. 2, we suppose $bin1 < bin2$. The symbol X_i is a changeable quantized AC coefficient in a block which belongs to S_C. m is the current to be embedded message bit of M. Besides of M, note that the values of $(bin1, bin2)$ and C are treated as side information which is going to be embedded into the pre-determined blocks.

The data extraction and cover image reconstruction is quite simple. First, the proposed method accesses the pre-determined blocks and retrieves the information about $(bin1, bin2)$ and C. Then, ABBS generates the S_C with respect to the side information. After located all the changeable coefficients($\widetilde{X}$) in the blocks in S_C, data extraction and cover image reconstruction is conducted as Eqs. 4 and 5, respectively.

$$m^{'} = \begin{cases} 0 & \widetilde{X_i} = bin1 \,\text{or}\, \widetilde{X_i} = bin2, \\ 1 & \widetilde{X_i} = bin1 - 1 \,\text{or}\, \widetilde{X_i} = bin2 + 1. \end{cases} \tag{4}$$

$$X_i^{'} = \begin{cases} \widetilde{X_i} - sign(\widetilde{X_i}) & \widetilde{X_i} \leq bin1 - 1 \,\text{or}\, \widetilde{X_i} \geq bin2 + 1, \\ \widetilde{X_i} & otherwise. \end{cases} \tag{5}$$

Where $m^{'}$ in Eq. 5 is the extracted message bits and $X_i^{'}$ is the reconstructed coefficients.

4 Experimental Results

In the experiments, two image sets are constructed where the images are from the BOSSbase 1.01 image library [2]. One is the training image set, which is employed to generate the training samples of KNN algorithm. The other one is the testing image set, whose elements are randomly selected from the BOSSbase. The two image sets are non-overlapped.

Note that the images in BOSSbase are raw files. Thus, these images should be compressed with JPEG standard. In this paper, we employed the JPEG library "Libjpeg" to compress images. It was developed by Tom Lane and the Independent JPEG Group (IJG), and Libjpeg is a wildly adopted library for processing JPEG images. To test the results in different payloads and different QFs, the training image set and testing image set is compressed with four different quality factors (QF = 70,80,90,100) respectively. For each QF level, 4 levels of payloads, 4k, 10k, 15k and 20k, are embedded into these images. In this case, we select 1000 images in BOSSbase randomly, and then, generated four image set by compressed them in the four QF levels respectively. 4 levels of payload will be tested at each QF level. These 16 image sets constitute the testing samples. On the other hand, according to the criteria of selecting a bins-pair which is introduced in Sect. 3.1, we elaborately select images of the remaining images of BOSSbase into 16 image sets. Obviously, each image set corresponds to a certain QF level and a payload level. These 16 image sets form the training samples of the KNN algorithm. The size of each training image set is influenced by the QF and payload level. For example, the possible bins-pairs of a 20k bits payload is smaller than the possible bins-pairs of a 4k bits payload, so the image sets corresponding to the two payloads have different number of images. In this paper, the average size of the 16 training image sets is 200.

In this paper, the performance of the proposed method is evaluated with respect to the stego image quality and the file size preservation. As we mentioned above, the proposed method is based on [5]. Thus, for fair comparison, the proposed method is compared with Huang et al.'s method, where the two methods belong to the same category of RDH methods for JPEG images.

4.1 Image Quality Comparisons

In the experiments, the peak signal-to-noise ratio(PSNR) is employed as the measurement of the stego image's visual quality, which is defined in Eq. 7.

$$MSE = \frac{1}{mn}\sum_{i,j}(X_{i,j} - \widetilde{X_{i,j}})^2. \tag{6}$$

$$PSNR = 10\log\frac{Max((X_{i,j})^2)}{MSE}. \tag{7}$$

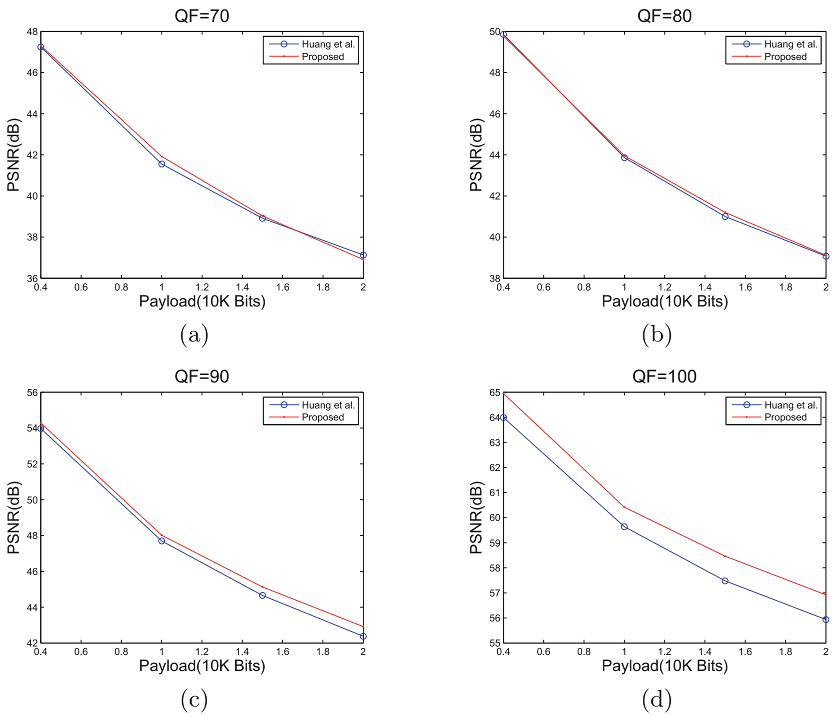

Fig. 7. Average PSNR values with different embedding payloads: (a) QF = 70, (b) QF = 80, (c) QF = 90, (d) QF = 100.

The comparison results are shown in Fig. 7. The four sub-figure (a)–(d) corresponds to different quality factors when performing JPEG compression to the test images. The horizontal axis is the embedding payload while the vertical axis is the average PSNR of the tested 1000 images.

Figure 7 indicates that both of methods achieves a decent PSNR value. Comparing with Huang et al.'s method, with the increasing QF level, the PSNR gain of our method is also increasing. When $QF = 100$ the proposed method gives at least 1 dB gain. Note that the results of the proposed method at certain QF levels similar to Huang et al.'s, especially when the payload is small, as shown in Fig. 7 (a) and (b). One possible reason is that the bins-pairs of the two method may be identical in many testing images. For example, when $QF = 70/80$, the optimal bins-pair selected by the proposed method is more likely to be $(-1,1)$, which is identical to Huang et al.'s selection.

4.2 File Size Preservation Comparisons

During the experiments, to evaluate the preservation of file size, we directly measure the increased file size between the original image file and the embedded image file.

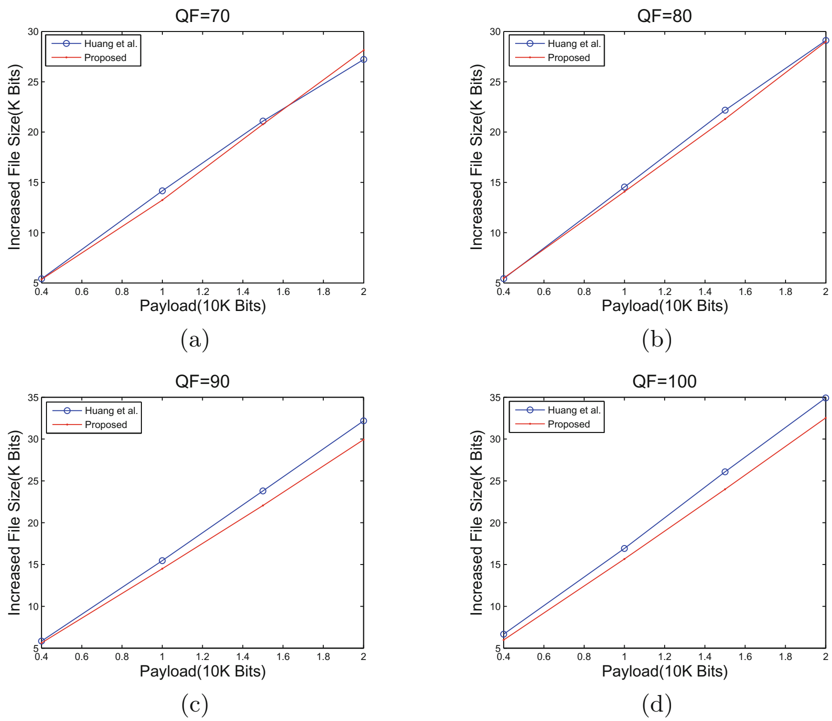

Fig. 8. Average increased file size with different embedding payloads: (a) QF = 70, (b) QF = 80, (c) QF = 90, (d) QF = 100.

The comparison results are shown in Fig. 8, which gives the average increased file size of 1000 test images with different JPEG compression quality factors and different payloads.

According to Fig. 8, as the payload and QF increases, the proposed method shows more improvements compared to Huang et al.'s method. When the payload is large and QF level is high, the proposed method demonstrates a significant advantage for preserving the file size. However, when the QF level is low, the performances are similar between the two methods. The reason is similar to that in Sect. 4.1.

5 Conclusion

In this paper, an adaptive reversible data hiding method for JPEG images is proposed. The proposed method firstly select the optical bins-pair for each cover image by adopting a KNN algorithm. Then, according to the bins-pair and message length, ABBS chooses the appropriate blocks for embedding the message bits. At last, ABBS embeds message bits by the standard histogram-shifting method. During the experiments, the proposed method can excellently keep the file size advantage and visual quality less. It demonstrates a superior performance compared to the state-of-the-art method.

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