Variable-Rate Quadtree-segmented Block Truncation Coding for Color Image Compression

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Abstract

A novel color image compression scheme based on block truncation coding is proposed in this paper. In this scheme, the quadtree segmentation technique is employed to partition the color image into variable-sized image blocks according to its block activities. Then, the block truncation coding scheme with the bit map omission technique is employed to encode the image blocks. According to the experimental results, the proposed scheme significantly cuts down the bit rates while keeping good reconstructed image qualities of the compressed color images.

1. Introduction

In the past few years, digital images are widely used in most multimedia applications. Generally, the digital images are stored in the compressed forms instead of the raw format to save the transmission bandwidth and the storage cost. Till now, several image coding schemes, such as vector quantization [1, 8], color image quantization [9, 15], block truncation coding (BTC) [16, 18], sub-band coding, JPEG, and JPEG 200, had been proposed. Among them, BTC is a commonly used image coding scheme for image compression.

BTC was first proposed to compress the grayscale images by Delp and Mitchell in 1979 [16]. It is also known as the moment preserving block truncation coding (MPBTC) because it preserves the first and second moments of image blocks. To encode each grayscale image, each image is partitioned into a set of non-overlapped image blocks of $n \times n$ pixels. The quantization threshold of each image block is calculated. According to the quantization threshold, all the pixels in each image block are classified into two groups. The grouping information of each image block is stored in the binary bit map of $n \times n$ bits. The quantization levels of these two groups are then computed. The compressed codes of each image block consist of one bit map and two quantization levels.

Till now, several modified BTC schemes, such as the third moment preserving quantization scheme [16], the mean squared error optimal quantization scheme [18], the absolute moment block truncation coding scheme (AMBTC) [19], and the generalized moment preserving quantization scheme [20], had been introduced. These schemes were introduced to hold different block properties. Among them, AMBTC had been proven to be the optimal scheme as far as the squared Euclidean distance measurement is concerned.

In 1984, Lema and Mitchell proposed the absolute moment block truncation coding scheme [19] for both grayscale and color image coding. In this scheme, the color image to be compressed is decomposed into three grayscale images. Then, each grayscale image is sequentially compressed. In other words, the compressed codes of a color image block by using AMBTC consist of three bit maps and six quantization levels.

Basically, BTC has the advantage of providing good image qualities of the compressed images. In addition, the image encoding/decoding procedures of BTC are very simple. That is why BTC is particularly suitable for real time and low computational cost multimedia applications. However, BTC consumes a high number of bit rates for image coding.

To reduce the bit rates of BTC for grayscale image compression, some schemes [21, 22] that employed the representative patterns to encode bit maps had been proposed. In addition, the interpolation of the bit map [23, 24] had been introduced. In these schemes, only partial bit maps are transmitted to the receiver. Then, the receiver executes the interpolation process to recover the bit maps that were not transmitted. Some BTC-based image coding schemes which used the quadtree segmentation technique [25, 26] had been proposed to cut down the required bit rates. Besides, the predictive coding technique had been employed to design BTC-based image coding schemes [27, 28]. Both the quadtree segmentation technique and the predictive coding technique exploit the spatial similarity among neighboring pixels in the images.

To cut down the bit rates of BTC for color image compression, the single bit map BTC scheme had been introduced in 1992 [29]. In single bit map BTC, one common bit map instead of three bit maps is taken to represent each color image block. Three rules, the majority rule, the luminance rule, and the weighted rule, had been designed to generate the common bit map for each color image block. The compressed codes of each color image block consist of one bit map and six quantization levels. The authors suggested that the weighted rule should be used to generate the common bit map because it achieves the best reconstructed image qualities according to the experimental results.

Currently, some improved image coding schemes [30, 31] based on single bit map BTC had been proposed. The color image compression by using moment preserving and block truncation coding technique (CICMPBTC) [30] had been proposed. The high correlations among quantization levels are exploited and the spectral identification code is designed to record the total number of quantizaiton levels transmitted to the receiver. In addition, the two-layer AMBTC scheme (TLAMBTC) [31] for color image compression had been proposed. TLAMBTC employs the single bit map AMBTC to compress the color images in the first layer. Then, the quantization levels are coded by AMBTC in the second layer. If the quantization levels to be coded in the second layer are very close to one another, the mean of the quantization levels is used to encode them.

In 2008, Hu *et al.*, proposed a novel color image coding scheme based on block prediction coding and AMBTC (AMBTC-BPC) [32]. The goal of AMBTC-BPC is to reduce the bit rates of AMBTC for color image coding. The block prediction coding technique is employed to exploit the block similarity. In addition, the bit map omission technique and the coding of the quantization levels are employed in AMBTC-BPC.

Several color image coding schemes based on BTC had been proposed so far. To further cut down the required bit rates while keeping good image qualities, a novel image coding scheme based on AMBTC is proposed in this paper. The rest of the paper is organized as follows. In Section 2, the review of the AMBTC scheme will be given. In Section 3, the newly proposed scheme will be introduced. The experimental results will be given in Section 4 to show if the proposed scheme indeed produces better performance. Finally, some conclusions will be given in Section 5.

2. Review on Absolute Moment Block Truncation Coding

In 1984, Lema and Mitchell proposed the absolute moment block truncation coding scheme [19] for grayscale and color image compression. The goal of AMBTC is to preserve the mean and the first absolute central moment of image blocks. Each grayscale image to be compressed is divided into a set of non-overlapping image blocks of $n \times n$ pixels. Each $n \times n$ image block can be viewed as an image vector of k dimensions, where $k = n \times n$. Each image block is sequentially processed in the order of left-to-right and top-to-down.

To compress each image block x, the block mean ($\bar{x}$) is calculated according to the following equation:

$$\bar{x} = \frac{1}{k} \sum_{i=1}^{k} x_i .$$
(1)

To generate the bit map (*BM*) of x, all the pixels in x are classified into two groups according to $\bar{x}$. If the intensity of one pixel is less than $\bar{x}$, it is classified as the first group and a corresponding bit with value 0 is stored in *BM*. Otherwise, it is classified as the second group and a corresponding bit with value 1 is stored in *BM*.

Pixels in the same group will be encoded by the same quantization level. Let a and b denote the quantization levels in the first and the second groups, respectively. These two quantization levels can be computed according to the following equations:

$$a = \frac{1}{k - q} \times \sum_{x_i < \bar{x}} x_i , \text{ and}$$
(2)

$$b = \frac{1}{q} \times \sum_{x_i \geq \bar{x}} x_i .$$
(3)

Here, q stands for the number of pixels whose values are greater than or equal to $\bar{x}$.

Each compressed image block forms a trio (a, b, *BM*) where each quantization level is stored in 8 bits. For each compressed block in AMBTC, a total of ($8+8+k$) bits are needed to store the compressed codes (a, b, *BM*). The required number of bit rates of AMBTC equals ($8+8+k$)/k bpp. For example, the number of bit rates of the AMBTC scheme equals 2 bpp when the block size k is set to 16.

In the image decoding procedure, each image block is to be rebuilt by using the received trio (a, b, *BM*). One pixel is reconstructed by quantization level a if a corresponding bit valued 0 is found in the bit map *BM*. Otherwise, it is recovered by quantization level b. After each pixel is recovered by either the quantization level a or b according to its retrieved bit map, the image block is then reconstructed. When each image block is sequentially recovered by using the above-mentioned step, the whole compressed image of the AMBTC scheme can be generated.

142	88	70	52
152	118	92	78
168	158	120	99
188	172	145	114

Figure 1. Image Block of 4×4 Pixels

An example of the image encoding procedure is described in the following. Figure 1 shows the original image block of 4×4 pixels. The block mean is first computed by using Eq. (1). In this example, the block mean equals 122.25. According to the block mean, the

bit map as shown in Figure 2(a) can then be generated. The quantization levels for these two groups are calculated by using Eqs. (2) and (3), respectively. These two quantization levels are 92 and 161, respectively. Finally, the compressed trio (92, 161, $(1000100011001110)_2$) is sent to the receiver.

To decode the compressed image, the compressed trio (92, 161, $(1000100011001110)_2$) is extracted. To recover each pixel, each bit in of the bit map is sequentially checked to recover the compressed pixel and the reconstructed image block is shown in Figure 2(b).
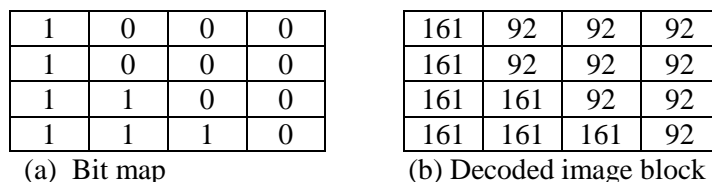
1	0	0	0
1	0	0	0
1	1	0	0
1	1	1	0

161	92	92	92
161	92	92	92
161	161	92	92
161	161	161	92

(a) Bit map (b) Decoded image block

Figure 2. The Image Encoding/Decoding Example

3. The Proposed Scheme

In this section, a quadtree-segmented AMBTC scheme with bit map omission is introduced. We call it AMBTC-QTBO. The quadtree segmentation technique will be introduced in Section 3.1. Next, the bit map omission technique will be discussed in Section 3.2. Finally, the detailed description of AMBTC-QTBO will be given in Section 3.3.

3.1. The Quadtree Segmentation Technique

The quadtree segmentation technique is a hierarchical segmentation technique that partitions one given image into variable-sized blocks based on the quadtree structure. Typically, the top-down approach is used because of its simplicity and flexibility. A series of binary decisions up to a set of different threshold values are made when the quadtree segmentation process is executed.

Usually, a block type classifier is employed to determine the block type. The block type classifier employs some statistical information such as block variance, averaged block absolute error, and so on, to determine the block activity. By choosing adequately controlling thresholds, different statistical measurements can be employed to control the quadtree segmentation process.
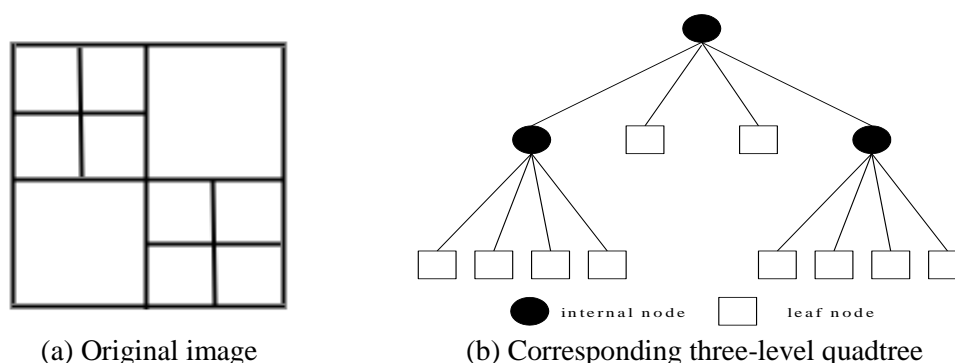

(a) Original image (b) Corresponding three-level quadtree

Figure 3. Example of a Three-level Quadtree

In general, the quadtree segmentation technique is simple and flexible. The question of how many levels should be used is important when performing quadtree segmentation. The more levels a quadtree contains, the more storage cost is required to record the position information of the quadtree structure.

In the proposed scheme, we use the absolute error between these two AMBTC quantization levels of each image block as the controlling threshold to illustrate the quadtree segmentation process. We assume that the image blocks with sizes larger than 16×16 are almost heterogeneous in their block activities in most digital images. Therefore, each image to be encoded is segmented into variable-sized blocks by a three-level quadtree.

An example of the quadtree segmentation process is depicted in Figure 3. The original image is listed in Figure 3(a). As shown in Figure 3(b), each internal node in the quadtree has four children emanating from it. In this example, five bits are needed to record the quadtree codes for an image block.

3.2. The Bit Map Omission Technique

The bit map omission [18] is a simple technique to reduce bit rates of BTC. The basic idea of the bit map omission technique is to omit the transmission of the bit map if the variance of one given image block is small, or equivalently, if the difference between its two quantization levels a and b is small. Only the block mean should be transmitted as the reconstruction level for the entire block in this case.

Basically, the mean of bit rates achieved by the bit map omission is highly dependent on the given image to be compressed. For most digital images with large uniform areas, this technique achieves a significant bit rate reduction with very little quality loss.

3.3. Quadtree-segmented AMBTC with Bit Map Omission (AMBTC-QTBO)

In the proposed scheme, one given color image is first decomposed into three grayscale images. Then, the quadtree segmentation technique is employed to partition each grayscale image into a set of variable-sized blocks. Three-level quadtree structures are imposed on the design of the coding scheme. In other words, only three kinds of blocks sized 16×16, 8×8, and 4×4 can be found. The reason why only three-level quadtree structures are used instead of four or more levels is that the image blocks with sizes larger than 16×16 are almost heterogeneous in block activities.

Algorithm of AMBTC-QTBO:
Step 1: Decompose the color image into three grayscale images.
Step 2: Partition each grayscale image into a set of non-overlapped image blocks of 16×16 pixels.
Step 3: Compute the block mean and two quantization levels a, b using AMBTC for each 16×16 image block.
Step 4: If $| a\text{-}b | \leq THQT$, then encode this 16×16 block using its block mean and go to Step 8. Otherwise, this block is sub-divided into four equal-size blocks of 8×8 pixels.
Step 5: Calculate the block mean and two quantization levels a, b using AMBTC for each 8×8 image block.
Step 6: If $| a\text{-}b | \leq THQT$, then encode this 8×8 block using its block mean and go to Step 8. Otherwise, this block is sub-divided into four equal-size blocks of 4×4 pixels.
Step 7: Calculate these two quantization levels a, b using AMBTC for each 4×4 block. If $| a\text{-}b | \leq THBO$, then this 4×4 block is encoded by its block mean. Otherwise, this 4×4 block is encoded by AMBTC.
Step 8: If there is still any block to be processed, go to Step 3.

In Step 2, each grayscale image is partitioned into a set of non-overlapped image blocks of 16×16 pixels. The block mean and the quantization levels a, b of each 16×16

image block are calculated. Then, the absolute distance between these two quantization levels is used to determine the block activity. We assume that one given image block is a complex block if a large absolute distance is found. The same statistical measurement is used in the successive quadtree segmentation process for image blocks sized 8×8 and 4×4.

In the quadtree segmentation process, the pre-defined threshold *THQT* is used to control whether or not each grayscale image block of 16×16 or 8×8 pixels is to be further sub-divided. In addition, another pre-defined threshold *THBO* is utilized to determine the block activity for 4×4 image blocks in the bit map omission technique. After the quadtree segmentation process, the variable-sized blocks will be compressed according to the following rules. For these smooth 16×16 and 8×8 blocks, they are encoded by their block means. For these smooth blocks of 4×4 pixels, the bit plane omission technique is employed to encode them. For the complex blocks of 4×4 pixels, they are encoded by AMBTC.

Table 1. Storage (unit: bit) Cost for Image Blocks in the Proposed Scheme

Storage Cost / Block Size		Number of indicators	Encoded Message		Total Bits
			Block Mean	BTC Trio	
16×16		1	8	N/A	9
8×8		2	8	N/A	10
4×4	Smooth	1	8	N/A	9
	Complex	1	N/A	(8+8+16)	33

Table 1 lists the storage cost for encoding image blocks of different sizes. To record whether each 16×16 image block is further sub-segmented or not, a 1-bit indicator is needed in the quadtree segmentation process. If one given 16×16 image block is sub-divided into four 8×8 image blocks, each of these four equal-size image blocks needs an additional one-bit indicator to record whether it needs to be sub-divided or not. In other words, two bits are needed to record the partition information for each 8×8 image block. For the 4×4 image blocks, only a one-bit indicator is required to record the block activity because the total number of 4×4 blocks can be determined using the partition information of those 16×16 and 8×8 blocks.

4. Experimental Results

To verify the performance of the proposed scheme, a variety of simulations had been performed on a personal computer with Intel Core i5 2.8 GHz CPU and 2 GB random access memory under the operation system of Microsoft Window 7. The experimental results listed below are the average performance of six color 512×512 images: "Airplane," "House," "Lena," "Pepper," "Splash," and "Tiffany." These testing images are shown in Figure 4. In the simulations, each testing image is partitioned into a set of non-overlapped image blocks of 4×4 pixels. In other words, there are 16384 image blocks in each testing image.

Results of the image qualities of AMBTC, MPBTC and single bit map AMBTC (AMBTC-SBM) are given in Table 2. Three rules including luminance rule, majority rule, and weighted rule are tested in AMBTC-SBM. The required bit rates of AMBTC and MPBTC are 6 bpp when the block size 4×4 pixels is used. It is shown that AMBTC achieves better image qualities than MPBTC. The required number of bit rates of AMBTC-SBM equals 4 bpp. The image quality loss of more than 3 dB is incurred by using AMBTC-SBM compared to that by AMBTC.

| (a) Airplane | (b) House | (c) Lena |

| (d) Pepper | (e) Splash | (f) Tiffany |

Figure 4. Six Testing Image of 512×512 Pixels

Table 2. Experimental Results of AMBTC, MPBTC and AMBTC-SBM

Methods Images	AMBTC (6 bpp)	MPBTC (6 bpp)	AMBTC-SBM (4 bpp)		
			Luminance	Majority	Weighted
Airplane	32.413	32.178	31.547	28.098	31.503
House	30.498	30.244	28.751	28.346	28.832
Lena	33.109	32.877	31.789	31.780	31.957
Pepper	32.701	32.464	28.981	28.174	29.547
Splash	36.158	35.946	30.422	30.338	30.741
Tiffany	35.308	35.112	29.814	27.623	29.213
Average	**33.365**	**33.137**	**30.217**	**29.060**	**30.299**

To understand the performance of the bit map omission technique, experimental results of the AMBTC scheme with the bit map omission technique are given in Figure 5. In the simulations, *THBO*'s are set to 5, 10, 15, …, and 30, respectively. Average results of 33.135 dB at 4.394 bpp, 32.072 dB at 2.754 bpp, and 31.229 dB at 2.335 bpp are obtained by using the AMBTC scheme with the bit map omission technique when *THBO*'s are set to 5, 15, and 25, respectively.

Experimental results of the image qualities and the bit rates of the proposed scheme without the bit map omission technique are listed in Tables 3 and 4, respectively. In the simulations, *THQT*'s are set to 5, 10, 15, …, and 30, respectively. Average image qualities of 33.331 dB, 31.999 dB, and 30.528 dB are obtained by using the proposed scheme without the bit map omission technique when *THQT*'s are set to 5, 15, and 25, respectively. Average bit rates of 5.451 bpp, 2.982 bpp, and 2.114 bpp are achieved when *THQT*'s are set to 5, 15, and 25, respectively.
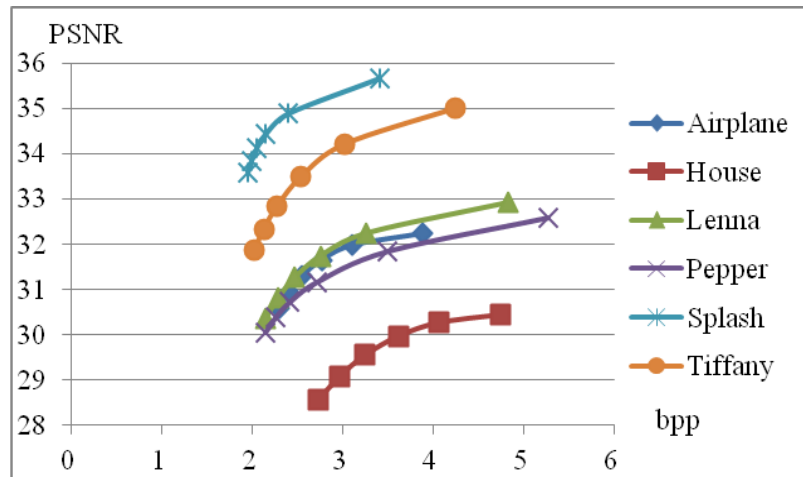
Figure 5. Results of the AMBTC Scheme with the Bit Map Omission Technique

Table 3. Image Qualities of the Proposed Scheme without Bit Map Omission

THQT / Images	5	10	15	20	25	30
Airplane	32.279	31.868	31.539	31.054	30.498	29.938
House	30.480	30.352	30.160	29.759	29.328	28.810
Lena	33.112	32.326	31.555	30.734	30.098	29.408
Pepper	32.709	32.306	31.379	30.569	29.876	29.286
Splash	36.094	34.803	33.921	33.234	32.541	32.022
Tiffany	35.310	34.486	33.439	32.294	30.829	29.903
Average	**33.331**	**32.690**	**31.999**	**31.274**	**30.528**	**29.895**

Table 4. Results of the Bit Rates of the Proposed Scheme without Bit Map Omission

THQT / Images	5	10	15	20	25	30
Airplane	4.175	2.944	2.621	2.303	2.049	1.877
House	5.103	4.353	4.003	3.59	3.278	3.000
Lena	5.989	3.669	2.786	2.247	1.947	1.695
Pepper	6.020	4.861	3.475	2.752	2.316	2.056
Splash	5.555	2.793	2.037	1.66	1.423	1.272
Tiffany	5.865	3.929	2.970	2.277	1.668	1.303
Average	**5.451**	**3.758**	**2.982**	**2.472**	**2.114**	**1.867**

Experimental results of the proposed scheme are given in Figure 6. In the simulations, *THQT*'s are set to 5, 10, 15, …, and 30, respectively. In addition, *THBO*'s are set to 5, 10, 15, …, and 30, respectively. According to the results, the reconstructed image qualities decrease as *THQT* increases in the proposed scheme. Similarly, the reconstructed image qualities decrease as *THBO* increases in the proposed scheme. However, the required bit rates decrease as *THQT* increases and as *THBO* increases. Average results of 33.171 dB at 4.407 bpp, 32.332 dB at 2.683 bpp, 31.514 dB at 1.980 bpp, 30.731 dB at 1.578 bpp, 29.950 dB at 1.309 bpp, and 29.266 dB at 1.118 bpp are obtained by using the proposed scheme.
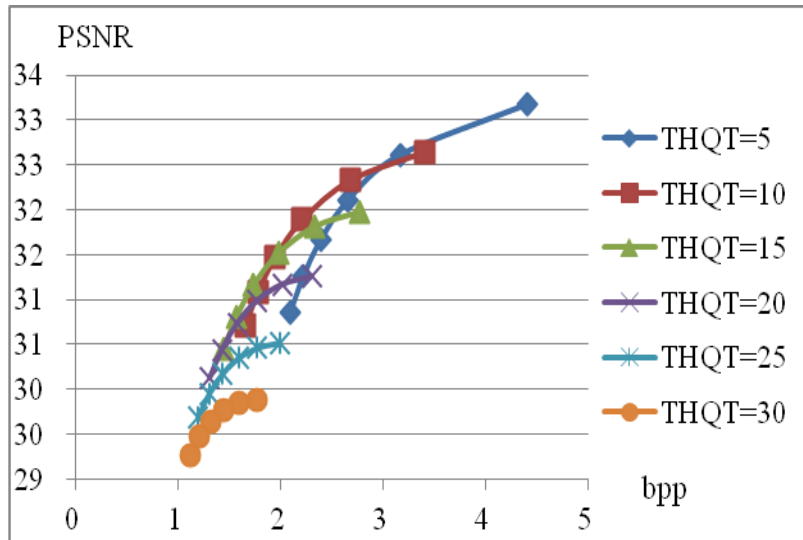
Figure 6. Average Results of the Proposed Scheme

To verify the efficiency of the proposed scheme (AMBTC-QTBO), the rate-distortion curves of the comparative methods are listed in Fig. 7. Among these comparative methods, CICMPBTC [30] and TLAMBTC [31] are based on a single bit map BTC. AMBTC-BPC is an improved coding scheme based on AMBTC. According to the results, it is obvious that the proposed scheme achieves better performance than both CICMPBTC and TLAMBTC. AMBTC-QTBO provides approximately the same performance as AMBTC-BPC. However, AMBTC-QTBO consumes less computational cost than AMBTC-BPC. That is because the block prediction coding process needs to find out whether a similar encoded block exists or not. In other words, the quadtree segmentation process used in the proposed scheme is much simpler than the block prediction process in AMBTC-BPC. According to the results, the state-of-art coding scheme JPEG achieves the best performance of these comparative methods.
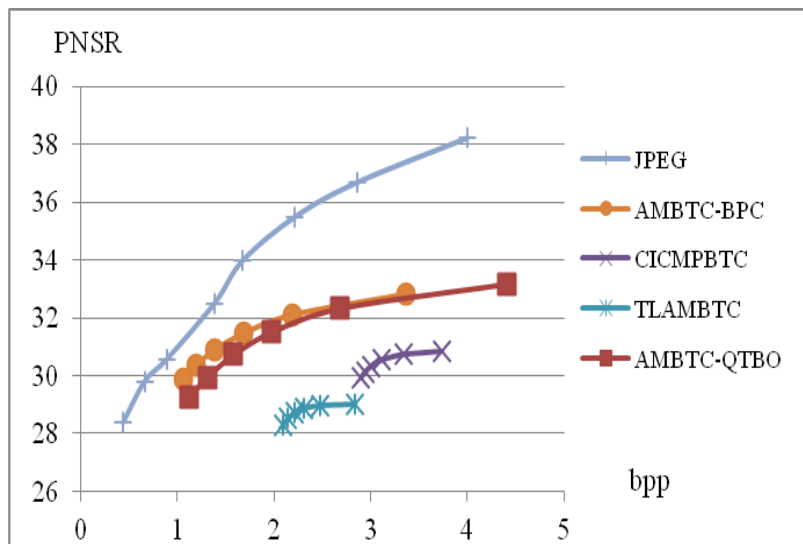

Figure 7. Rate-distortion Curves of the Proposed Scheme and other Comparative Methods

5. Conclusions

In this paper, a novel color image compression scheme based on BTC had been proposed. In the proposed scheme, AMBTC instead of MPBTC is employed because AMBTC is proven to be the optimal scheme based on squared Euclidean distance measurement. In addition, the quadtree segmentation technique and the bit map omission technique are used in the proposed scheme to cut down the bit rates.

The selection of control threshold values for *THQT* and *THBO* has great influences on the performance of the proposed scheme. Basically, the threshold values of *THQT* and *THBO* should be set according to the user's requirements. To achieve a better image quality using the proposed scheme, small values of *THQT* and *THBO* should be used at the cost of higher bit rates. By choosing adequately controlling thresholds, good image qualities of the compressed images can be obtained by the proposed scheme while keeping low bit rates.

Acknowledgements

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