Predictive Grayscale Image Coding Scheme Using VQ and BTC

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Abstract. A predictive image compression scheme that combines the advantages of vector quantization and moment preserving block truncation coding is introduced in this paper. To exploit the similarities among neighboring image blocks, the block prediction technique is employed in this scheme. If a similar compressed image block can be found in the neighborhood of current processing block, it is taken to encode this block. Otherwise, this image block is encoded either by vector quantization or moment preserving block truncation coding. A bit-rate reduced version of the proposed scheme is also introduced. According to the experimental results, it is shown that the proposed scheme provides better image quality at a low bitrate than these comparative schemes.

Keywords: image compression, vector quantization, block truncation coding, bit map coding

1. Introduction

Vector quantization (VQ) and block truncation coding (BTC) are two commonly used schemes for image compression. In 1980, Linde et al. introduced the concept of VQ [1]-[3]. VQ can be divided into three parts: the codebook design process, the image encoding process, and the image decoding process. The goal of the codebook design process is to generate a set of representative vectors, also called codewords, used in both image encoding and decoding processes. The set of representative codewords is sometimes called codebook. From the literature, the LBG algorithm [1] is the most commonly used method for codebook design.

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In the image encoding process of VQ, the image to be compressed is first partitioned into a set of non-overlapped image blocks of $n \times n$ pixels. To compress one image block, the closest codeword in the codebook is searched. Then the index of the closest codeword in the codebook is taken as the compressed code. Generally, the squared Euclidean distance (SED) is used in finding the closest codeword in the codebook of one given image block.

In the image decoding process of VQ, the image block should be reconstructed by using a same codebook as used in the image encoding process and the received indices. To rebuild the image block, the received index is used to recover the compressed image block. By performing a simple table lookup operation, the compressed image block can be reconstructed.

VQ is widely used because it has a simple decoding structure and requires a low bitrate. However, a lot of computational costs are needed in the codebook design procedure and the image coding procedure. To speed up the codebook design process using the LBG algorithm, the concept of integral projection had been introduced in [4]. In this scheme, an average of 98% computation time reduction can be achieved. Additionally, several schemes [5]-[7] had been introduced to accelerate the codebook search process of VQ.

To reduce the bitrate of VQ, Hu et al. employed the concept of quadtree segmentation [8] to explore the variable-block-sized segmentation of image blocks. Besides, a predictive codebook search algorithm [9] using a mean-sorted codebook had been introduced in 2000. In 2001, the sub-sampling vector quantization (SVQ) scheme [10] had been proposed to low down the bitrate of VQ.

In 1979, Delp et al. introduced the block truncation coding (BTC) scheme to compress the grayscale images [11]-[12]. It is also called moment preserving block truncation coding (MPBTC). In BTC, the grayscale image to be compressed is first divided into a set of non-overlapped image blocks. Then, two quantization levels and one bit map are used to represent the compressed image block. These two quantization levels are designed to preserve the first and second moments of these image blocks. In 1984, Lema et al. [13] introduced the absolute moment block truncation coding scheme (AMBTC) to preserve the block mean values and the first absolute moment of image blocks.

In general, BTC has the advantages of requiring very low computational cost and providing good reconstructed image quality. However, a high bitrate is needed in BTC. In 1991, Nasiopoulos et al. designed a set of image-independent edge patterns to represent the bit map [14] so that the bitrate of BTC can be reduced. The authors suggested that 128 visual patterns were used to encode the bit map. In 1995, Ramana and Eswaran proposed a simple interpolative scheme for BTC bit map coding [15]. In this scheme, only half of the bits in the bit map are transmitted to the decoder. To recover the whole bit map, a set of rules based on interpolation is used.

In 2003, Hu proposed a low bit-rate AMBTC scheme [16] based on quadtree segmentation. In this scheme, a three-level quadtree structure is used to divide the given grayscale image into image blocks of $16 \times 16$, $8 \times 8$, and $4 \times 4$ pixels. Image blocks of $16 \times 16$ and $8 \times 8$ pixels are encoded by their mean values. Image blocks of $4 \times 4$ pixels are compressed by AMBTC with bit map coding using 64 frequent patterns. Besides, an improved MPBTC scheme [17] that exploits the similarities among neighboring block had been introduced in 2003. In this scheme, the block search order coding technique is used to determine whether one given image block can be encoded by its neighboring encoded blocks.

Several modified schemes that employ a mix of the VQ scheme and the BTC scheme had been developed so far [18]-[22]. Some schemes that employed VQ to process the quantization levels and bit maps of BTC had been introduced [18]-[19]. In 1995, Mohamed et al. proposed a hybrid VQ-BTC scheme [20] that employed the bit map of BTC to partition the image block into two vectors. Then these
two vectors are encoded by VQ using the corresponding codebook with the same dimensions. In 1999, Chang et al. proposed three hybrid image compression schemes [21] based on VQ and BTC. In 2000, Hu et al. proposed a low bit-rate image compression [22] scheme using VQ and BTC. In this scheme, the concept of quadtree segmentation is used to explore the variable-block-sized segmentation of image blocks.

To sum up, we observe that VQ works quite well for the smooth blocks while BTC performs well for the complex blocks. Besides, a high degree of similarity exists among neighboring blocks in most digital images. To take advantages of VQ and BTC, a novel grayscale image compression scheme based on VQ and BTC is proposed in this paper. The rest of the paper is organized as follows. In Section 2, some related schemes of hybrid methods based on VQ and BTC will be reviewed. In Section 3, the newly proposed scheme will be introduced. The experimental results are listed in Section 4 to show if the proposed scheme indeed produces better performance. Finally, some discussions and conclusions will be given in Section 5.

2. Related Schemes

In this section, we shall review the quadtree-segmented image coding schemes based on vector quantization and block truncation coding [20]. In 2000, Hu et al. proposed three hybrid image coding schemes based on VQ and AMBTC [22]. In these schemes, the quadtree segmentation technique is employed to exploit the high correlation among neighboring image blocks. In this scheme, the image to be compressed is first partitioned into a set of non-overlapped image blocks of $16 \times 16$ pixels. Then, the quadtree segmentation technique is performed into partition the $16 \times 16$ image block variable-sized blocks depend on its block activity. Three possible block sizes are $16 \times 16$, $8 \times 8$ and $4 \times 4$ pixels. In the quadtree segmentation process, all pixels in the $16 \times 16$ image block are classified into two groups according to the mean value of blocks. The first group consists of the pixels whose values are smaller than the block mean value, and the second group consists of the pixels whose values are equal to or greater than the block mean value. The absolute difference value of the two mean values of these two groups is computed and compared to a pre-defined threshold to decide whether a given block needs a split or not. The same process is performed recursively until the smallest allowable block size is encountered. Fig. 1 depicts an example of three-level quadtree.

After the quadtree segmentation technique is performed on the image block of $16 \times 16$ pixels, the resultant image blocks of $16 \times 16$ and $8 \times 8$ pixels are compressed by the sub-sampling vector quantization (SVQ). Since these $16 \times 16$ and $8 \times 8$ blocks tends to be quite smooth, each of them is sub-sampled into a $4 \times 4$ block and then compressed by the traditional VQ scheme. Besides, the image blocks of $4 \times 4$ blocks are compressed by AMBTC. That is because the authors assume that these $4 \times 4$ blocks should be quite complex. Therefore, AMBTC is used to compress these complex $4 \times 4$ blocks.

The authors introduced three hybrid VQ-AMBTC schemes that share the same encoding/decoding procedures. The major difference of these schemes is that they use different methods to process the complex blocks of $4 \times 4$ pixels. In the first scheme, called Scheme A, the original AMBTC is used to encode the complex blocks. The second scheme, called Scheme B, employs the interpolative bit map coding [15] to process these complex blocks. Finally, Scheme C uses the bit map coding using frequent patterns [14] to compress these complex blocks.
3. The Proposed Scheme

A predictive image compressed scheme based on VQ and BTC is proposed. The goal of the proposed scheme is to combine the advantages of VQ and BTC to provide good image quality at a low bitrate. To achieve the goal, the block prediction technique is introduced to exploit the inter-correlation of image blocks. The flowchart of the proposed encoding procedure is depicted in Fig. 2.

3.1. The Image Encoding Procedure

In the image encoding procedure, the given image is first partitioned into a set of non-overlapped image blocks of $n \times n$ pixels. Each image block can be viewed as a $k$-dimensional image vector where $k = n \times n$. In this scheme, we suggest that the size of image blocks is set to $4 \times 4$ pixels. These image blocks are processing in left-to-right and top-to-bottom order. We observe that the neighboring pixels in most digital images are quite similar. It means that the neighboring image blocks also tend to be similar. To make use the high correlation among neighboring image blocks, the block prediction technique is used in the proposed scheme.

To encode each image block, we need to determine whether the block prediction technique can be used to encode this block or not. In the block prediction technique, if a similar encoded block can be found in the predefined search range $sr$, image block $x$ can be encoded by its similar encoded block. If two and four encoded neighbors are searched in the block prediction technique, two and three bits are needed to represent the found similar neighbor, respectively. Search order of the encoded neighbors of current processing block $x$ in the block prediction technique is depicted in Fig. 3. Note that 1-bit indicator is needed to distinguish whether the block prediction technique is used or not.
Figure 2. Flowchart of the proposed encoding procedure
Let $EB_i$ denote the $i$-th encoded block of $k$ pixels in the search range, the squared Euclidean distance between $x$ and $EB_i$ can be calculated according to the following equation.

$$d(x, EB_i) = \sum_{j=1}^{k} (x_j - EB_{ij})^2.$$ (1)

We need to calculate $sr$ squared Euclidean distances and then find out one encoded block with the minimal squared Euclidean distance $d_{min}$ to the image block $x$. If $d_{min}$ is less than or equal to the predefined threshold $TH_{SED}$, the corresponding encoded block is used to represent $x$. Here, the similarity threshold $TH_{SED}$ is used to control the degree of block similarity in the block prediction technique.

If no encoded neighbor in the specific range $sr$ is similar to $x$, we need to determine whether VQ or BTC should be used to compress this block. Two guidelines are used here. First, if one image block can be well processed by VQ with little distortion, it should be encoded by VQ. Second, if the difference between the distortions incurred by VQ and BTC is quite small, VQ instead of BTC should be used to encode this block.

First, the image block $x$ is processed by VQ and the distortion between $x$ and its decoded block is stored in $dist_{VQ}$. If the calculated distortion $dist_{VQ}$ is less than or equal to $TH_{VQ}$, $x$ is then encoded by VQ. Here, $TH_{VQ}$ is a predefined threshold that is used to control the tolerant distortion of VQ. If $dist_{VQ}$ is greater than $TH_{VQ}$, we need to check whether BTC can be used to improve the image quality of VQ. $x$ is then processed by BTC and the distortion between $x$ and its decoded block is stored in $dist_{BTC}$. Based on the second guideline, we need to check whether $dist_{BTC}$ is greater than $(dist_{VQ} + TH_{DIFF})$. $TH_{DIFF}$ denotes the allowable difference between distortions generated by VQ and BTC. If $dist_{BTC}$ is greater than $(dist_{VQ} + TH_{DIFF})$, $x$ is compressed by VQ. Otherwise, $x$ is compressed by BTC. To sum up, there are three different approaches to encode image blocks in this scheme. First, some image blocks are encoded by the block prediction technique with similar encoded neighbors in the specific search range $sr$. Second, some image blocks that are quite smooth or have approximately the same encoded blocks of VQ and BTC are encoded by VQ. Finally, the remaining blocks are compressed by BTC. The required storage cost for these three approaches are listed in Table 1.

To further cut down the storage cost of the proposed scheme, a bitrate-reduced version of the proposed scheme is introduced. To cut down the bitrate, the improved version of the proposed scheme aims to reduce the storage cost of the image blocks compressed by BTC. The quantization levels and the bit map of each compressed block of BTC are further processed.
Table 1. Storage cost of different encoding approaches of the proposed scheme when codebook sized $N_c$ is used and the image block size equals $k$

<table>
<thead>
<tr>
<th>Encoding Methods</th>
<th>Cost</th>
<th>Indicator Cost (bits)</th>
<th>Indicator Codes</th>
<th>Total Cost (bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block Prediction Technique</td>
<td>1</td>
<td>‘0’</td>
<td></td>
<td>$1 + \log_2 sr$</td>
</tr>
<tr>
<td>Vector Quantization</td>
<td>2</td>
<td>“10”</td>
<td></td>
<td>$2 + \log_2 N_c$</td>
</tr>
<tr>
<td>BTC</td>
<td>2</td>
<td>“11”</td>
<td></td>
<td>$2 + (8+8+k)$</td>
</tr>
</tbody>
</table>

As we know, the quantization levels of BTC can be derived by the block mean value $\bar{x}$ and the variance $\sigma$ of each image block. We employ the following rules to encode $\bar{x}$ and $\sigma$.

$$\bar{x} = \bar{x}/4.$$  \hfill (2)

$$\sigma = \begin{cases} 
\frac{\sigma}{3}, & \text{if } \sigma \leq 45 \\
45, & \text{otherwise}
\end{cases}$$  \hfill (3)

Using these rules lock mean value and variance of each image block are coded with 6 and 4 bits, respectively.

In the improved scheme, the bit map coding using visual patterns is employed to cut down the storage cost of the bit maps in BTC-encoded blocks. If a set of representative patterns can be designed, the required bitrate of BTC can be reduced with a slightly image quality loss. In this scheme, 64 visual patterns of $4 \times 4$ bits as shown in Fig. 4 are used to process the BTC bit maps. These patterns are derived based on the analysis of possible edge directions. The closest pattern of each bit map is determined and the index of the closest pattern is recorded. Here, the closest pattern is the one with the minimal Hamming distance to the input bit map. The index of the closest is then used and transmitted to the receiver.

The reason why we use 64 visual patterns to encode the bit maps of the complex image blocks is that only slightly improvement of image quality is achieved when 128 visual patterns are used in the proposed scheme. Besides, only the bit maps of the complex blocks instead of all the blocks are processed using these 64 edge patterns. By using 64 edge patterns to encode the bit map for each image block, only 6 bits are needed to represent the bit map.

3.2. The Image Decoding Procedure

The goal of the image decoding procedure is to recover the compressed image. Suppose the given image is partitioned into a set of image blocks of 16 pixels and a VQ codebook of $N_c$ codewords is used. To reconstruct each compressed block $x$, we need to find out the encoding approach used in the image encoding procedure. By retrieving the first two bits of the received compressed codes, we can determine
the encoding approach that is used to encode the current decoding block. If the content of the first bit equals \(0\), it indicates that \(x\) is compressed by the block prediction technique. By extracting the successive \(\log_2 sr\) bits from the received compressed codes, we can determine which one of the encoded block in the search range is the similar encoded block of \(x\). This encoded block is used to reconstruct \(x\).

If the content of the two bits equals \(10\), it indicates that \(x\) is compressed by VQ. By extracting the successive \(\log_2 Nc\) bits from the received compressed codes, we can find out the index of the closest codeword in the codebook. The corresponding codeword in the codebook is used to reconstruct \(x\).

If the content of the two bits equals \(11\), it indicates that \(x\) is compressed by BTC. By extracting the successive 32 bits from the received compressed codes, we can get these two quantization levels and the bit map. Then, the BTC decoding procedure is executed to reconstruct \(x\). By using one of the three decoding approaches described above, one compressed block of \(k\) pixels can be reconstructed. By repeatedly performing the same process, all the image blocks can be reconstructed to recover the compressed image.
Using the above decoding procedure, we can successively decode the compressed image by using the proposed scheme. Now we turn to describe how to decode the compressed image of the improved proposed scheme. The major difference between them is the way to recover the BTC-encoded image blocks. To recover one image block that was compressed by BTC, (6+4+6) bits are extracted from the received compressed codes so that we can get the 6-bit $\bar{x}$, 4-bit $\sigma$ and 6-bit index of the frequent bit map.

Remember that the block mean value and the variance $\sigma$ of each image block are encoded with 6 bits and 4 bits, respectively in the image encoding procedure. To transform the mean value and the variance of each image block back to 8-bit values, the following rules are used.

$$\bar{x} = (\bar{x} + 0.5)/4.$$  \hspace{1cm} (4)

$$\sigma = \begin{cases} 
\sigma + 0.5 \times 3, & \text{if } \sigma \leq 45 \\ 45, & \text{otherwise} 
\end{cases}$$  \hspace{1cm} (5)

These two 8-bit values are then used to calculate the quantization levels. In addition, the 6-bit index of the frequent bit map is used to recover the bit map of this image block. When the bit map and these two quantization levels are available, the BTC decoding procedure is trigged to recover the compressed image block.

4. Simulation results

To verify the performance of the proposed scheme, several simulations have been executed on an IBM compatible PC with Linux OS. These VQ codebooks used in the simulations are designed by the accelerated version of the LBG algorithm [4] using five training images "Airplane", "Boat", "Lena", "Sailboat", and "Toys". To fairly compare the performance of these comparative schemes, six test images "Airplane", "Girl", "Lena", "Pepper", "Tiffany", and "Toys" as shown in Fig. 5 are used in the simulations. Among these six images, three of them are inside the training set of VQ while the others are outside the training set. All the grayscale images used are of $512 \times 512$ pixels. Each grayscale image of $512 \times 512$ pixels is partitioned into a set of non-overlapped image block of $4 \times 4$ pixels.

Experimental results of the image quality of related BTC schemes and VQ with different codebook sizes are listed in Table 2. Six test images are used to measure the average performance of these schemes. BTC-BC represents BTC with bit map coding using frequent patterns [14]. In the simulations, we designed 64 edge patterns to compress the bit map. In addition, BTC-BI denotes the BTC with bit map interpolation [15].

Experimental results of the image quality and the bitrate of three hybrid VQ-AMBTC schemes [22] are listed in Table 3 when the VQ codebook sized 256 is used. We find that Scheme A provides better image quality than that of Schemes B and C. But, a higher bitrate is required in Scheme A. Additionally, the image quality of Scheme C outperforms Scheme B while keeping a lower bitrate.

Experimental results the block prediction coding technique for BTC and VQ are shown in Table 4. Two possible search ranges valued 2 and 4 are used in the simulations. A codebook of 256 codewords that is generated previously by the accelerated version of the LBG algorithm [4] is used in the simulations. Besides, the improved codebook search algorithm [7] is used to find the closest codeword in the codebook for the image block encoded by VQ. According to the results shown in Table 4, we find that a great deal
of bitrate can be reduced with a little image degradation when a suitable threshold value is used in the block prediction technique. The threshold used in the block prediction technique should not be too large because more image degradation is occurred when a large threshold is used. Based on the results, we suggest that $sr$ is set to 2 in the proposed scheme.

Table 2. Experimental results of image quality (PSNR) of related BTC schemes and VQ with different codebook sizes

<table>
<thead>
<tr>
<th>Methods</th>
<th>BTC 2.0 bpp</th>
<th>BTC-BI 1.5 bpp</th>
<th>BTC-BC 1.375 bpp</th>
<th>VQ-128 0.438 bpp</th>
<th>VQ-256 0.5 bpp</th>
<th>VQ-512 0.563 bpp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airplane</td>
<td>33.027</td>
<td>30.898</td>
<td>31.313</td>
<td>29.333</td>
<td>30.582</td>
<td>31.578</td>
</tr>
<tr>
<td>Girl</td>
<td>34.559</td>
<td>32.665</td>
<td>30.096</td>
<td>29.807</td>
<td>31.174</td>
<td>31.971</td>
</tr>
<tr>
<td>Lena</td>
<td>33.466</td>
<td>31.369</td>
<td>31.869</td>
<td>29.607</td>
<td>31.373</td>
<td>32.248</td>
</tr>
<tr>
<td>Pepper</td>
<td>33.843</td>
<td>31.927</td>
<td>32.240</td>
<td>28.987</td>
<td>30.728</td>
<td>31.408</td>
</tr>
<tr>
<td>Tiffany</td>
<td>36.796</td>
<td>33.070</td>
<td>34.093</td>
<td>28.517</td>
<td>30.318</td>
<td>30.733</td>
</tr>
<tr>
<td>Toys</td>
<td>33.011</td>
<td>30.778</td>
<td>31.555</td>
<td>27.570</td>
<td>29.920</td>
<td>31.156</td>
</tr>
<tr>
<td>Average</td>
<td><strong>34.117</strong></td>
<td><strong>31.785</strong></td>
<td><strong>31.861</strong></td>
<td><strong>28.970</strong></td>
<td><strong>30.683</strong></td>
<td><strong>31.516</strong></td>
</tr>
</tbody>
</table>
Table 3. Experimental results of Schemes A, B, and C in [22]

<table>
<thead>
<tr>
<th>Images</th>
<th>Thresholds</th>
<th>(10,10)</th>
<th>(20,20)</th>
<th>(30,30)</th>
<th>(40,40)</th>
<th>(50,50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheme A</td>
<td>PSNR</td>
<td>32.962</td>
<td>31.213</td>
<td>29.704</td>
<td>28.118</td>
<td>27.217</td>
</tr>
<tr>
<td></td>
<td>BR</td>
<td>1.094</td>
<td>0.675</td>
<td>0.471</td>
<td>0.322</td>
<td>0.238</td>
</tr>
<tr>
<td>Scheme B</td>
<td>PSNR</td>
<td>31.211</td>
<td>30.085</td>
<td>28.968</td>
<td>27.785</td>
<td>26.946</td>
</tr>
<tr>
<td></td>
<td>BR</td>
<td>0.846</td>
<td>0.528</td>
<td>0.372</td>
<td>0.257</td>
<td>0.193</td>
</tr>
<tr>
<td>Scheme C</td>
<td>PSNR</td>
<td>31.645</td>
<td>30.393</td>
<td>29.179</td>
<td>27.915</td>
<td>27.032</td>
</tr>
<tr>
<td></td>
<td>BR</td>
<td>0.784</td>
<td>0.491</td>
<td>0.347</td>
<td>0.241</td>
<td>0.165</td>
</tr>
</tbody>
</table>

Table 4. Results of block prediction technique for BTC and VQ with different search range \( sr \)

<table>
<thead>
<tr>
<th>Methods</th>
<th>TH_{SED}</th>
<th>400</th>
<th>800</th>
<th>1200</th>
<th>1600</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTC</td>
<td>( sr = 2 )</td>
<td>PSNR</td>
<td>33.434</td>
<td>32.745</td>
<td>32.155</td>
<td>31.638</td>
</tr>
<tr>
<td>BTC</td>
<td>( sr = 2 )</td>
<td>BR</td>
<td>1.112</td>
<td>0.907</td>
<td>0.794</td>
<td>0.719</td>
</tr>
<tr>
<td>BTC</td>
<td>( sr = 4 )</td>
<td>PSNR</td>
<td>33.392</td>
<td>32.677</td>
<td>32.073</td>
<td>31.540</td>
</tr>
<tr>
<td>BTC</td>
<td>( sr = 4 )</td>
<td>BR</td>
<td>1.073</td>
<td>0.861</td>
<td>0.747</td>
<td>0.673</td>
</tr>
<tr>
<td>VQ</td>
<td>( sr = 2 )</td>
<td>PSNR</td>
<td>30.603</td>
<td>30.504</td>
<td>30.207</td>
<td>29.973</td>
</tr>
<tr>
<td>VQ</td>
<td>( sr = 2 )</td>
<td>BR</td>
<td>0.350</td>
<td>0.300</td>
<td>0.273</td>
<td>0.255</td>
</tr>
<tr>
<td>VQ</td>
<td>( sr = 4 )</td>
<td>PSNR</td>
<td>30.595</td>
<td>30.435</td>
<td>30.242</td>
<td>30.011</td>
</tr>
<tr>
<td>VQ</td>
<td>( sr = 4 )</td>
<td>BR</td>
<td>0.368</td>
<td>0.323</td>
<td>0.299</td>
<td>0.284</td>
</tr>
</tbody>
</table>

To determine the controlling threshold \( \text{TH}_{SED} \) used in the proposed scheme, average results of the proposed scheme with \( \text{TH}_{VQ} = -1 \) and \( \text{TH}_{DIFF} = 0 \) are listed in Fig. 6. A VQ codebook of 256 codewords is used in the simulations. If one image block is not processed by the similar block prediction technique, it is encoded by either BTC or VQ that generate the smaller image distortion. Based on the results, we find that the best image quality is achieved when \( \text{TH}_{SED} \) equals 0. Besides, the image quality decreases as the increase of \( \text{TH}_{SED} \). A significant reduction of bitrate is achieved when \( \text{TH}_{SED} \) equals 400 while keeping good reconstructed image quality. We suggest that \( \text{TH}_{SED} \) should be set to 400 in the proposed scheme to provide good image quality. If the goal is to provide acceptable image quality, a large \( \text{TH}_{SED} \) value such as 800 or 1200 should be used in the proposed scheme.

To choose a suitable \( \text{TH}_{VQ} \) value in the proposed scheme, average results of image quality and bitrate of the proposed scheme when \( \text{TH}_{SED} \) equals 400 and \( \text{TH}_{DIFF} \) equals 0 are listed in Fig. 7. The image quality decreases when a large \( \text{TH}_{VQ} \) value is used. Based on the results, we suggest that \( \text{TH}_{VQ} \) should be set to 400 or 800 to provide good reconstructed image qualities. If the goal is to provide acceptable image quality at a lower bitrate, a large \( \text{TH}_{VQ} \) value such as 1200 or 1600 should be used in the proposed scheme.
To understand the effects of using $\text{TH_{DIFF}}$ to reduce the bitrate of the proposed scheme, average results of image quality and bitrate of the proposed scheme with different $\text{TH_{DIFF}}$ values are given in Fig. 8. To simplify the selection of threshold values, $\text{TH_{SED}}$ and $\text{TH_{VQ}}$ are set to 400 and 800, respectively. When a large $\text{TH_{DIFF}}$ value is used in the proposed scheme, we find that most image blocks are encoded by VQ. The achieved image quality decreases along with the decrement of the bitrate. To provide good image quality using the proposed scheme, a small $\text{TH_{DIFF}}$ value should be used.

According to the results we find that an average image quality of 32.708 dB is achieved at 0.558 bpp when $\text{TH_{SED}} = 400$, $\text{TH_{VQ}} = 800$ and $\text{TH_{DIFF}} = 800$ are used in the proposed scheme. Compared to VQ at 0.563 bpp, there is an image quality gain of 1.192 dB of the proposed scheme. Note that the codebook used in the simulations is of 256 codewords.
Figure 8. Results of the proposed scheme with different TH_{DIFF} values when TH_{SED} equals 400 and TH_{VQ} equals 800

Figure 9. Results of the improved version of the proposed scheme with different TH_{VQ} values when TH_{SED} equals 400 and TH_{DIFF} equals 0

According to the results shown in Table 2, an average image quality of equals 31.785 dB at 1.5 bpp is obtained in BTC-BI. Besides, an average image quality of 31.861 dB at 1.375 bpp is achieved in BTC-BC. An average image quality of 31.867 dB is achieved at 0.421 bpp when TH_{SED} = 800, TH_{VQ} = 2400 and TH_{DIFF} = 800 are used in the proposed scheme. Compared to BTC-BI and BTC-BC, the bitrate reduction of the proposed scheme equals to 1.079 bpp and 0.954 bpp, respectively.

Experimental results of the bit-rate reduced version of the proposed scheme are given in Figs. 9 and 10. Compared to the proposed scheme, the improved version of the proposed scheme achieves a
slightly worse image quality at a lower bitrate. To determine the controlling threshold $T_{H_{SED}}$ used in the improved scheme, average results of the proposed scheme with $T_{H_{VQ}} = -1$ and $T_{H_{DIFF}} = 0$ are listed in Fig. 9. A VQ codebook of 256 codewords is used in the simulations. According to the results, we find that a significant reduction of bitrate is achieved when $T_{H_{VQ}}$ equals 800.

![Figure 10. Results of the improved version of the proposed scheme with different $T_{H_{DIFF}}$ values when $T_{H_{SED}}$ equals 400 and $T_{H_{VQ}}$ equals 800](image)

Table 5. Experimental results of the execution times (unit: sec.) of related schemes, the proposed scheme (PS) and the improved version of the proposed scheme (IPS)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Airplane</td>
<td>0.067</td>
<td>0.417</td>
<td>1.283</td>
<td>0.100</td>
<td>0.300</td>
<td>0.017</td>
<td>0.033</td>
</tr>
<tr>
<td>Girl</td>
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<td>0.383</td>
<td>1.383</td>
<td>0.083</td>
<td>0.350</td>
<td>0.012</td>
<td>0.017</td>
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<tr>
<td>Lena</td>
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<td>0.417</td>
<td>1.433</td>
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<td>0.300</td>
<td>0.017</td>
<td>0.017</td>
</tr>
<tr>
<td>Pepper</td>
<td>0.050</td>
<td>0.417</td>
<td>1.383</td>
<td>0.083</td>
<td>0.300</td>
<td>0.015</td>
<td>0.033</td>
</tr>
<tr>
<td>Tiffany</td>
<td>0.067</td>
<td>0.400</td>
<td>1.217</td>
<td>0.050</td>
<td>0.300</td>
<td>0.017</td>
<td>0.017</td>
</tr>
<tr>
<td>Toys</td>
<td>0.067</td>
<td>0.400</td>
<td>1.417</td>
<td>0.067</td>
<td>0.233</td>
<td>0.014</td>
<td>0.017</td>
</tr>
<tr>
<td>Average</td>
<td><strong>0.064</strong></td>
<td><strong>0.407</strong></td>
<td><strong>1.353</strong></td>
<td><strong>0.077</strong></td>
<td><strong>0.297</strong></td>
<td><strong>0.015</strong></td>
<td><strong>0.022</strong></td>
</tr>
</tbody>
</table>

To understand the effects of using $T_{H_{DIFF}}$ to reduce the bitrate of the improved scheme, average results of image quality and bitrate of the proposed scheme with different $T_{H_{DIFF}}$ values are given in Fig. 10. An average image quality of 31.193 dB is achieved at 0.388 bpp when $T_{H_{SED}} = 400$, $T_{H_{VQ}} = 800$ and $T_{H_{DIFF}} = 2400$ are used in the improved scheme. Based on the results in Table 2, the VQ scheme with a codebook of 256 codewords, the average image quality is 30.683 dB at 0.5 bpp. The improved version of the proposed scheme provides better performance than VQ. Table 5 lists the results of the execution times of these comparative schemes. In Table 5, VQ-PS denotes the VQ with full-search
algorithm. Besides, VQ-IMPS denotes the accelerated version of codebook search algorithm [7]. To save the space, we only list the results of the proposed scheme and its bit-rate improved version with the longest execution times. In other words, the thresholds $TH_{SED}$, $TH_{VQ}$, and $TH_{DIFF}$ used in the proposed scheme are set to 400, 400, 400, respectively. Besides, we only list the results of Scheme C [22] because it requires the largest computational cost among these three schemes.

![Decoded images of "Airplane" and "Lena" using VQ, Scheme C, and the proposed scheme](image)

From the results shown in Table 5, it is shown that VQ with the full search algorithm consumes the highest computational complexity. BTC requires little computational cost but BTC with bit map coding using 64 frequent patterns needs higher execution times. Among these comparative schemes, the proposed scheme requires little computational cost because most image blocks can be processed by the block prediction technique and the accelerated VQ codebook search algorithm [7] is used. The improved version of the proposed scheme requires a slightly higher computational cost than the proposed scheme. The consumed execution times of the improved scheme are less than that of BTC.

Some decoded images of "Airplane" and "Lena" are given in Fig. 11 to verify the visual quality of the proposed scheme. The problem of false contours can be found in the decoded images of Scheme C because the quadtree segmentation technique is used in Scheme C [22]. The decoded images of the proposed scheme provide the best visual quality and the differences between the original images can hardly be observed.
5. Conclusions

A novel grayscale image compression scheme based on VQ and BTC is introduced. This scheme exploits the block similarities among neighboring image blocks to improve the bitrate of traditional hybrid methods based on VQ and BTC. If the image distortion generated by VQ is quite small, VQ instead of BTC is used to process the image block. If the image distortion incurred by VQ is slightly larger than that by BTC, we suggest that VQ should be used to encode such image block. By choosing adequate controlling thresholds, the proposed scheme provides good image quality at a low bitrate. According to the results we find that an average image quality of 32.708 dB is achieved at 0.558 bpp when \( \text{TH}_{\text{SED}} = 400, \text{TH}_{\text{VQ}} = 800 \) and \( \text{TH}_{\text{DIFF}} = 800 \) are used in the proposed scheme. To further reduce the required bitrate of the proposed scheme, an improved version is also introduced. By employing the coding of quantization levels and bit map coding of frequent patterns, the required bitrate is thus reduced. An average image quality of 31.193 dB is achieved at 0.388 bpp when \( \text{TH}_{\text{SED}} = 400, \text{TH}_{\text{VQ}} = 800 \) and \( \text{TH}_{\text{DIFF}} = 2400 \) are used in the improved scheme. It provides better performance than VQ with a codebook of 256 codewords. According to the results in Table 5, the proposed scheme and its improved version both consume little time of computation. That is because a large portion of image blocks is processed in the similar block prediction technique. Besides, the accelerated VQ search algorithm [7] is used in the proposed scheme. In other words, the proposed scheme is quite suitable for real-time multimedia applications.

6. Acknowledgment

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References


