Improved JPEG Scheme Based on Adaptive Block Encoding

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Abstract-In this paper, a new adaptive image compression scheme based on JPEG was proposed to improve the image quality of the JPEG baseline sequential image compression codec. In this scheme, the Hough transformation technique is employed as an edge-oriented classifier to categorize image blocks into four classes. Different types of image blocks are processed by different quantization and encoding ways for achieving an effective compression performance. In order to preserve edge information, the adaptive quantization tables based on the human visual system and zig-zag scan sequences are used. For both objective and subjective visual image quality, simulation results show that the performance of the proposed scheme is comparable to that of other compared schemes.

Keywords: JPEG; Quantization table; Hough transformation; Adaptive image compression

1. Introduction

Research in image compression has been conducted for many years by many researchers [1,2,3]. The importance of image compression has not diminished but has magnified due to the rapid growth of heavy volumes of image and video data that are transmitted over a narrow bandwidth network or that are stored in limited storage devices in many multimedia applications. Many messages are represented as digital images or in videos for transmission or storage.

Till now, several image compression schemes such as vector quantization (VQ) [4,5,6,7], block truncation coding (BTC) [8,9], JPEG [10], and so on, have been introduced. VQ, BTC, and JPEG belong to block-based coding schemes because the images to be compressed are divided into non-overlapping image blocks and then processed. Generally, edge information cannot be fully preserved in VQ and JPEG. BTC can preserve edge information well; however, it usually has the defect of the appearance of jagged edges in the decoded image since all the pixels in each block are truncated into only two quantization levels.

In general, VQ has the advantages of requiring a low bit rate and of having a simple decoding structure. But the major drawback of VQ is that a great deal of computational cost is consumed in both the codebook design and image encoding. BTC has the advantages of achieving good reconstructed image quality while requiring low computational cost. But a high bit rate is required in BTC. JPEG provides a different approach to encoding digital images by processing the DCT coefficients of each image block instead of the original pixel values. It is known that JPEG is able to provide high compression rates and is especially suitable for the purpose of compressing continuous-tone still images, like scenic photos in Internet applications.

However, the edge information of a given image cannot be fully preserved in JPEG. From the research on the human visual system (HVS) [10,11], it has been noted that people understand image contents by recognizing edge features when looking at an image. Perceptual edges correspond to significant intensity and orientation variations in an image. Since the edge information is quite important in the human vision system, the research toward preserving the edge information of compressed images is worth conducting. Some adaptive image compression methods have been proposed [12,13,14]. In this paper, we propose an adaptive image compression scheme to improve the JPEG baseline sequential image compression.

The remainder of this paper is organized as follows. In Section 2, a review of related image compression schemes is given. In Section 3, we shall address our proposed adaptive image compression scheme. Then the simulation results are provided in Section 4. Finally, conclusions are drawn in Section 5.

2. Previous Works

In this section, we first briefly review the JPEG baseline sequential codec as it relates to the investigation in this paper. Then, we outline previous work related to this article.

2.1 JPEG Baseline Sequential Codec

JPEG image compression supports four modes of image compression: baseline sequential, progressive, lossless, and hierarchical. The JPEG baseline sequential image compression codec is a lossy image compression method that allows the quality of a
reconstructed image to be controlled by a chosen quality factor. The main encoding steps of JPEG consist of three parts, which are discrete cosine transform (DCT), quantization, and entropy encoding.

In the JPEG baseline sequential image compression codec [15], a given input image is first decomposed into $N \times N$ non-overlapping blocks, where $N$ is always 8 in JPEG, and a two-dimensional forward DCT (FDCT) transformation is applied to each block. The FDCT is used to transform all pixels in each image block into frequency coefficients and is utilized for the analysis of the importance of the high and low frequency coefficients, which correspond to the area of high variation and low variety, respectively.

After transformation, the DCT coefficients of each block are subsequently scalar quantized for efficient storage. Each coefficient $C(i, j)$ is quantized by a corresponding quantum value in the quantization table $Q$, i.e.

$$C'(i, j) = \text{Round} \left( \frac{C(i, j)}{Q(i, j)} \right).$$  \hspace{1cm} (1)

Note that the quantization table is not fixed in JPEG according to its standard. This flexibility is left to the application for use when necessary.

The final encoding step in JPEG is entropy encoding. In this step the DC coefficients are handled by using the differential pulse code modulation (DPCM) technique. All of the quantized coefficients are arranged into the zig-zag sequence to help with efficient entropy coding.

The baseline codec uses the Huffman coding technique to realize the entropy encoding according to the JPEG proposal. The final entropy encoding step in the encoder achieves an extra compression by encoding the quantized DC and AC coefficients losslessly using their statistical characteristics.

The decoding procedure of JPEG is the inverse of the encoding procedure. The main decoding steps of JPEG consist of three parts. They are inverse DCT (IDCT), inverse quantization, and entropy decoding.

The first decoding step in JPEG is the entropy decoding procedure. The encoded DC and AC coefficients are decoded by resolving the same Huffman Table used in the encoding steps.

The second inverse quantization step is to multiply the same quantum value used in the quantization step with the decoded DC and AC coefficients, i.e.

$$C'(i, j) = C'(i, j) \times Q(i, j).$$  \hspace{1cm} (2)

Reconstructed value $C'(i, j)$ is the approximation value of the original DCT coefficient $C(i, j)$. The last decoding step in JPEG is the IDCT process.

2.2 Adaptive Image Compression Scheme Using Local Pattern Information

In 2002, Pan proposed the adaptive image compression scheme using local pattern information, which was a noticeable image compression scheme [13]. In this scheme, the energy distribution in the DCT domain is used to decide the edge patterns of sub-blocks, and these DCT coefficients are then adaptively quantized. It first uses three energy intensity measures in the frequency domain to classify sub-blocks into horizontal edge blocks, vertical edge blocks, diagonal edge blocks, and non-edge blocks. A penalty of 2 bits per block indicating the types of sub-blocks is included in the header of the compressed file.

Then, four types of HVS-based adaptive quantization tables are designed to adapt to the different sub-blocks. The adaptive quantization tables used are based on the results of the study of HVS [10]. In [10], the usefulness of HVS for achieving better perceptual image quality has been highlighted. Lastly, the zigzag scan paths of quantized DCT coefficients are adjusted for further compressing in the entropy encoding step.

3. The Proposed Scheme

The goal of the proposed scheme is to improve the JPEG baseline sequential codec by exploiting the edge information in the DCT domain. In the design of the proposed scheme, the key processing steps are the design of the classifier, adaptive quantization table, and zig-zag scan sequence arrangement.

In this scheme, the Hough Transformation (HT) [16] is employed as an edge-oriented classifier to categorize each image block into four classes, that is, diagonal edge blocks, horizontal edge blocks, vertical edge blocks, and non-edge blocks, based on its edge pattern. We devised four quantization tables to adapt to the above-mentioned four corresponding image blocks based on HVS so as to take advantage of the results in [10]. We also reordered the zig-zag scan sequences for the different block types.

The encoding flow chart of the proposed scheme is depicted in Fig. 1. In this scheme, input image blocks are classified into the four classes, namely, horizontal edge blocks, vertical edge blocks, diagonal edge blocks, and non-edge blocks, by the edge-oriented classifier, based on their edge pattern.

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The classified class index of each image block is fed into the quantization and zig-zag scan reordering entropy coding steps for selecting the appropriate quantization table and reordering the zig-zag scan sequence, respectively. It also has to be stored in the header of the compressed bitstream for the usage of the decoder in the quantization and zig-zag scan reordering entropy decoding steps, as shown in Fig. 2.

![Fig. 2. The decoding steps of the proposed adaptive image compression scheme.](image)

Except for the block classification steps and the adaptive quantization and zig-zag scan reordering entropy coding steps, the other processing steps are the same as those for the original JPEG baseline sequential image encoder.

The decoding processing steps in the proposed image compression scheme are the inverse of the encoding procedure, except for the steps of extracting each block class index from the header in the decompressed bit stream. The block class index is then used in the inverse quantization and zig-zag scan reordering entropy decoding step to select the correct reordering zig-zag decoding sequence quantization table. The other processing steps are also the same as the original JPEG baseline sequential image decoder.

The edge-oriented classifier is realized by applying HT. HT is a robust and commonly used method for detecting lines in images. An advantage of HT is that the range of the parameter angle is between 0° and 180°. It is more effective than other simpler schemes to apply HT to classify the image block into vertical edge, horizontal edge, diagonal edge block, and non-edge according to the detected angle. HT uses the voting technique in a partitioned parameter space to detect lines. The edge orientations of image blocks are identified during HT. The basic idea is as follows: the method parameterizes a line in the form:

\[ r = x_k \cos \theta + y_k \sin \theta \]

where \( r \) is the normal distance and \( \theta \) is the normal angle from the origin. The above equation is a mapping of an edge point \((x_k, y_k)\) to a sinusoidal curve \( r = x_k \cos \theta + y_k \sin \theta \) in the discrete \( r\theta \)-parameter space, which is referred to as accumulator and initialized with zeros.

Let the quantized interval of parameter \( \theta \) and \( r \) be \( Q_\theta \) and \( Q_r \), respectively. Each edge point \((x_k, y_k)\) is mapped into the \( r\theta \)-parameter space, which has a number of \( Q_\theta \times Q_r \) cells. A vote is cast for the accumulator cells that are intersected by the sinusoidal curve \( r = x_k \cos \theta + y_k \sin \theta \) at variable \( \theta \) values. After the voting process for each edge point is completed, all the accumulator cells with a total number of votes that surpasses a predetermined threshold are considered as representing lines in the image. The idea has been extended to extract arbitrary shapes [17].

The classifier in the proposed scheme categorizes an image block into four classes based on the orientation of the lines detected by HT. The four classes of an image block are horizontal edge block, vertical edge block, diagonal edge block, and non-edge block. Edges are pixels where intensity changes abruptly within an image. They can be detected with many edge detectors [16]. In our scheme, an image block of a grayscale image is first detected for edges by the Sobel edge detector [16], and the identified edges constitute an edge map. Then the edge points are extracted from the edge map and fed into HT to determine the block class.

The processing procedure of the classifier is given as follows:

1. The magnitude gradient \( g(x, y) \) of the pixel located at coordinate \((x, y)\) is measured by performing a 2-D spatial gradient convolution operation with masks of the Sobel edge detector.
2. After all the edges in the image block have been detected, the pixel location \((x, y)\) is identified as an edge point if \( g(x, y) \) surpasses a threshold \( t_e \). Finally, an edge map \( E(x, y) \) is generated, where \( E(x, y) \) is defined as

\[
E(x, y) = \begin{cases} 1, & (x, y) \in S_e \\ 0, & \text{otherwise} \end{cases}
\]

where

\[
S_e = \{(x, y); g(x, y) > t_e\}.
\]

3. Extract all edge points to serve as the input data of HT from the edge map \( E(x, y) \).
4. Apply HT for classifying the image block into four classes. Set accumulator \( A(r, \theta) = 0 \), initially.
5. Calculate all quantized normal distances \( r \) for all sampled normal angles \( \theta \).
6. Increment \( A(r, \theta) = A(r, \theta) + 1 \).
7. Repeat Steps (5) to (6) for all edge points on the edge map \( E(x, y) \).
8. The cell in \( A(r_e, \theta_e) \) having the highest count is associated with a line whose normal distance is
$r_k$ and whose normal angle is $\theta_k$. The image block with a total number of edge pixels that is smaller or equal to a lower bound $E_{\ell}$ is categorized as a non-edge block; otherwise, the image block with the significant normal angle $\theta_k$ is classified into a predefined class.

The location of a line detected by HT can be stored at a feature file for indexing in a content-based image retrieval system. The benefits of considering image compression and indexing at the same time can be seen in [2].

Once image blocks are classified into four classes based on their edge orientations, they can be best fitted for compression by designing appropriate quantization tables for them. Typically, a quantization table is designed in such a way that the larger quantum values are located in the lower right areas and the smaller quantum values are located in the upper left areas in the DCT coefficients matrix because energies are concentrated at low frequencies. It is well known that DCT coefficients reflect different image energy distributions. More significant coefficients concentrated in the left vertical area in a DCT coefficients matrix reflect a horizontal edge in the image block.

In other words, the coefficients located in the left vertical area in a DCT coefficients matrix are more important than others in a horizontal edge block. It is more effective to fine quantize along these areas, starting from DC, then along other areas for achieving better visual quality. On the other hand, the more significant coefficients concentrated in the top horizontal area in a DCT coefficients matrix correspond to a vertical edge in the image block. It is adequate to fine quantize along these areas starting from DC. More significant coefficients concentrated in the diagonal area correspond to a diagonal edge in the image block. The finer quantization direction is along the diagonal area starting from DC. It is not proper to use the sample luminance quantization table in JPEG, as shown in Fig. 3(a), to conform to the principles aforementioned.

<table>
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<td>15 15 15 15 15 16 18 20 24</td>
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<td>14 13 16 24 40 57 69 56</td>
<td>15 15 16 17 18 20 23 27</td>
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<tr>
<td>14 17 22 29 51 87 80 62</td>
<td>15 15 17 20 22 25 29 33</td>
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<td>18 22 37 56 68 109 103 77</td>
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</tr>
<tr>
<td>72 92 95 98 112 100 103 99</td>
<td>23 24 27 33 44 60 82 108</td>
</tr>
</tbody>
</table>

(a) (b)

Fig. 3. (a) The sample luminance quantization table in JPEG, and (b) The HVS-based luminance quantization table with $q = 15$

In our scheme, the adaptive quantization tables are derived from a HVS-based luminance quantization table since the finding in [10,13] facilitates the promotion of the quality of the decompressed image. We adopted the step-size of the uniform quantizer $q = 15$, as shown in Fig. 3(b).

The adaptive quantization tables used in our scheme are shown in Fig. 4, which are derived from Fig. 3(b) using the transformation formulas (4) to (7). This transformation agrees with the principles mentioned earlier. By preserving the edge orientation information in an image block with the proper quantization table, an effective improvement of image quality results, thereby coding more bit rates to more significant coefficients and less bit rates to less important coefficients. Visually least significant information is discarded in the adaptive quantization step for the objective of increasing the number of zero-values, which facilitates run-length coding.

$Q_h^k = Q_h^v \times 0.15 \times (y - 7) + 1.65$, \hspace{1cm} (4)

$Q_v^k = Q_v^h \times 0.15 \times (x - 7) + 1.65$, \hspace{1cm} (5)

$Q_{h,v}^k = Q_{h,v}^v \times (0.15 \times (x - y) - 7) + 1.65$, \hspace{1cm} (6)

$Q_{y}^{v,n} = Q_{y}^{v,n} \times 0.7$, \hspace{1cm} (7)

where $Q_{xy}^{h,v}$ is the HVS-based quantization table with $q = 15$, which is shown in Fig. 3(b), $Q_{xy}^{h}$, $Q_{xy}^{v}$, $Q_{xy}^{d}$, and $Q_{xy}^{n}$ denote the new quantization tables for adapting to horizontal, vertical, diagonal, and non-edge blocks, respectively.

There are three kinds of zig-zag reordering sequences used in our scheme to adapt to different edge-oriented image blocks. The reordering sequences are derived from the finding in the scheme presented in [13]. The diagonal edge block and non-edge blocks are encoded with the zig-zag scan path since the coefficients in the top left area are significant for these two types of image blocks. The zig-zag reordering sequence in Fig. 5 is used to adapt to the horizontal and vertical edge blocks, respectively. The numbers in Fig. 5 indicate the scan sequence in ascending order. This zig-zag reordering sequence effectively decreases the storage size for encoding different edge-orientation image blocks compared to using the zig-zag scan path in JPEG.

4. Simulation Results

The adaptive image compression that adapts to the image blocks can achieve desirable gains evaluated in both objective and subjective visual image quality as compared to the JPEG sequential baseline sequential image compression codec. This has been shown in the scheme presented in [13]. We conducted some simulations on six standard gray scale images, namely, “Barbara”, “Lax”, “Plane”,

- 602 -
“Goldhill”, “Milkdrop”, and “Woman2” and compared image quality with the VQ and the scheme in [13].

\[ Q_{\theta} = \begin{cases} 0 & \text{if } \theta < 0 \\
\frac{\theta}{180} \mod 1 & \text{if } 0 \leq \theta < 180 \\
1 & \text{if } \theta \geq 180 
\end{cases} \]

and \( \theta_0 \) and \( \theta_1 \) denote the original and the used in the classifier of our

\[ D_{ij} = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (O_{ij} - D_{ij})^2 \]

\[ PSNR = 10 \log_{10} \left( \frac{255^2}{\sum_{ij} (O_{ij} - D_{ij})^2} \right) \text{dB}. \]

Here \( O_{ij} \) and \( D_{ij} \) denote the original and the decompressed pixel values, respectively. \( M \) and \( N \) denote the weight and height of the images. A larger PSNR value indicates a smaller image quality distortion between the original image and the decompressed image.

For simplicity and effectiveness, the quantized intervals \( Q_{\theta} \) and \( Q_{\theta} \) used in the classifier of our simulations were 4 and 20, respectively, in the experiments of this paper. These quantization intervals of \( Q_{\theta} \) and \( Q_{\theta} \) can be quantized more elaborately for achieving a different performance in classification. An image block with a total number of edge pixels, which is smaller or equal to 1, i.e. \( E_i = 1 \), was classified into non-edge blocks. Image blocks in which \( E_i > 1 \) were categorized by their normal angle \( \theta_k \). An image block with \( \theta_k = 0^\circ \) (or \( 180^\circ \)), \( \theta_k = 90^\circ \), \( \theta_k = 45^\circ \) (or \( 135^\circ \)) was classified into horizontal edge blocks, vertical edge blocks, and diagonal edge blocks in the paper.

The reconstructed image quality coded at 0.25 bpp comparing the PSNR in our proposed scheme, the VQ scheme, and the scheme in [13] (denoted in “Adaptive JPEG”) is shown in Table 1. We also compared the performance of a low bit rate coded at 0.5 bpp, which is shown in Table 2.

The six reconstructed test images of the standard images are given in Fig. 6 in which the visual quality can be compared with the original images shown in Fig. 6. Simulation results show that the overall visual quality and PSNR gains of the test images can be obtained, as compared to other image compression schemes.

From the observation of our simulation results, our scheme can achieve improved image quality in subjective visual effect and objective PSNR assessment, compared to the VQ scheme and the scheme in [13], by including 2 penalty bits per block in the header of the compressed bit stream. These 2 bits can be further reduced to between 1.15 and 1.65 bits using the Huffman coding [13]. Moreover, our scheme has a side extension advantage in its image indexing capability because it can store the extracted block edge features in a feature file while compressing an image.

This characteristic of simultaneously possessing adaptive image compression and indexing capabilities was not proposed in the scheme in [13] and other adaptive image methods. This benefit comes from utilizing HT as an image block classifier. After being transformed by HT, the extracted line location and orientation in an image block can be used to characterize an image in a context-based image retrieval application.

5. Conclusions

An adaptive image compression scheme based on JPEG was proposed to improve the image quality of
the JPEG baseline sequential image compression codec. When the preservation of significant edges in an image was considered, the useful HVS result was incorporated in the design of the adaptive quantization tables, which were used to adapt to the different edge feature image blocks and preserve significant edge information. These four different edge orientation image blocks were identified by the HT-based classifier. The scan sequence of quantized coefficients in a DCT block was further reordered in order to obtain more efficient encoding performance.

Due to the use of an adequate edge-oriented image block classifier, new quantization tables, and zig-zag scan sequence, the proposed scheme achieved satisfactory image quality gains in objective and subjective visual measurement from the simulation indications, compared to the VQ and the scheme in [13]. The main purpose of this paper is to offer an alternate approach for the quality improvement of JPEG coding. The quality may be increased by varying the threshold value for the Sobel filter or other parameters. Also, it is interesting to further investigate the impact of the different classification of a block which contains the same numbers of vertical edges as horizontal edges. The investigation of that will be our future work. Additionally, the proposed scheme has a side extension advantage of adaptive image compression and indexing simultaneously. This extension provides potential for further study.

<table>
<thead>
<tr>
<th>Images</th>
<th>VQ</th>
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<td>36.46</td>
<td>36.59</td>
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Fig. 6. Visual quality comparisons of the original images and images compressed at 0.25 bpp
References


