THREE-SIDED SIDE MATCH FINITE STATE VECTOR QUANTIZATION

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ABSTRACT

Several effective low bit rate still image compression methods have been presented in these two years, such as SPHIT [9], Hybrid VQ [7], Wu and Chen method [10]. These methods exercise the analysis techniques (wavelet or subband) before distributing the bit rate to each piece of image, thus the tradeoff between bit rate and distortion can be resolved. In this paper, we try to propose a simple but comparable method that adopts the technique of side match VQ only.

Side match vector quantization (SMVQ) is an efficient VQ coding scheme for low bit rate coding. Conventional side match (two-sided) utilizes the codeword information of two neighboring blocks to predict the state codebook of an input vector. In this paper, we propose a hierarchical three-sided side match finite-state vector quantization (HTSMVQ) method that can (1) make the state codebook size as small as possible, it can be reduced to 1 if the prediction is performed perfectly; (2) improve the prediction quality for edge blocks; (3) regularly refresh the codewords to alleviate the error propagation of side match. In the simulation results, the image "Lena" can be coded with PSNR 34.682 dB at 0.25 bpp. It is better than SPIHT, EZW, FSSQ and hybrid VQ with 34.1, 33.17, 33.1 and 33.7 dB, respectively. At the bit rate lower than 0.15 bpp, only the enhanced versions of EZW perform better than our method about 0.14 dB.

1. INTRODUCTION

Vector quantization(VQ) [1-2] is a well-known block encoding technique for image compression. Previous works pay much attention to the modification of VQ techniques for achieving a higher compression ratio. Among these studies, the finite-state VQ (FSVQ) [3-4] provides one of the effective results because it exploits the correlation between neighboring vectors to reduce each index size via contracting the codebook to be a smaller one, called the state codebook. Thus, each input vector is encoded using its own state codebook only. Practically, each state codebook is partially selected from a common codebook (called the super codebook) through the use of the encoder state that is determined by correlation. Briefly, FSVQ can maintain the image quality of a large VQ codebook and attain the low bit rate of a small VQ codebook.

Side match VQ (SMVQ) [3] is a sort of FSVQ that utilizes the codeword information of two neighboring blocks, upper block B_U and left blocks B_L, to predicate the state codebook of an input vector B. The above prediction may be poor if the correlation between B_U, B_L and B are not high enough; it is particularly serious for encoding the edge blocks. Under such circumstances, the quantization distortion might be unacceptably large because the state codewords selected by SMVQ are not close to the input vector. The problem might be solved if the other two neighboring blocks, the bottom block B_B and the right block B_R, are contributed in prediction. In other words, the conventional two-sided side match can be replaced by three-sided or even four-sided side match. However, during coding block B, block B_B and block B_R are not produced yet, so we have to encode these blocks first.

The concept of variable-rate SMVQ is commonly used in the SMVQ implementation, it dynamically changes the size of state codebook to fit the variance of block characteristics, that is, the high-variation block will have larger candidate set and the low-variation block only needs smaller candidate set. In particular, the state codebook size of a low-variation block can set as 1 (the index is no long needed to be transmitted in this case) if the side match can predicate perfectly.

In this paper, we indicate that the three-sided (or four-sided) side match is suitable for non-edge blocks as well as for edge blocks. The former can be used to reduce the bit rate and the latter can help improving the prediction. We propose a three-sided side match finite-state vector quantization (TSMVQ) method that includes a three-sided prediction and a sampling arrangement. This arrangement decides which subset of the blocks are transmitted to decoder in the first phase. A primary feature of TSMVQ is that the large amount of indices in the second phase need not be transmitted since their prediction by our three-sided side match are quite well, thus the decoder can recover them individually. To reduce the bit rate of the first phase, a hierarchical structure of TSMVQ is proposed. Beside, for further reducing the bit rate, two lossless coding schemes, the index grouping algorithm [5] and the Huffman coding, are applied to compress the resulting index stream.

The rest of this paper is organized as follows. Section 2 reviews the side match finite-state VQ and presents our three-side side match method. Our proposed algorithms, TSMVQ and hierarchical TSMVQ, are presented in Section 3. Section 4 demonstrates the simulation results. Finally, conclusions are given in Section 5.

2. SIDE MATCH VQ

Side match VQ is a kind of FSVQ that uses the attribute of spatial contiguity across block boundary to establish the state. It suggests that the state codebook be composed of the set of codewords whose boundary pixels are much similar to the side pixels of the neighboring blocks. In the implementation, conventionally, two-sided side match is commonly used because the blocks are coded in raster-scan order. In experiences, the two-sided side match prediction may become inadequate if the block is an edge block. Three-sided or four-sided side match is the right way of acting the excellent prediction.

2.1 Two-Sided Side Match

Conventional SMVQ uses the side information of upper, B_U, and left, B_L, neighboring blocks to produce the state codebook for each input vector B. In SMVQ implementation, the state codebook size is commonly not fixed to fit the variance of block characteristics, that is, the high-variation blocks will have larger size state codebook and the low-variation blocks will have smaller size state codebook. However, two limitations arise: (1) the state codebook size can not be further reduced and (2) the prediction can not work well for edge blocks. Besides, SMVQ induces error propagation inherently, i.e. the quantization errors will feed back to next state, thus bring down the prediction quality. Therefore, construct a better prediction scheme is desired for SMVQ, especially for the low bit rate coding.

2.2 Three-Sided and Four-Sided Side Match

Intuitive modification of side match utilizes not only the upper and left blocks but also the right and/or bottom neighboring block(s). We call the new schemes as *three-sided* or *four-sided side match*. To perform above side match schemes, all three or four surrounding blocks must be encoded previously. Such blocks are denoted as *pre-coded* block in the rest of the paper. In coding these pre-coded blocks, FSVQ is no longer appropriate, since the surrounding blocks are not available, however, regular VQ is still accessible.

In this study, we adopt three-sided side match to perform the SMVQ prediction. The pre-coded blocks are arranged in Figure 1, that is a regular interleaving arrangement with 4:1 sampling. In this sampling arrangement, the shaded blocks are the pre-coded blocks that will be coded by regular VQ, and the blank blocks will be coded by the three-sided side match scheme after the pre-coded blocks are coded, the block marked as "×" are also pre-coded to create the initial state.

In our implementation, there are three kinds of prediction. Consider Figure 1 again. Type 1 and Type 2 use the side information (pixels colored as black) of three neighboring blocks, (upper, left, right) and (upper, left, bottom), respectively. Type 3 uses the side information (pixels colored as black) of two neighboring blocks (upper, left) and four extra corner points. For convenience, we call the collection of side pixels, colored as black for anyone type, as the side vector. In prediction, the three-sided side match procedure first decides the type and uses the appropriate side vector to evaluate the distortion of each codeword in super codebook, then constructs the state codebook for further usage.

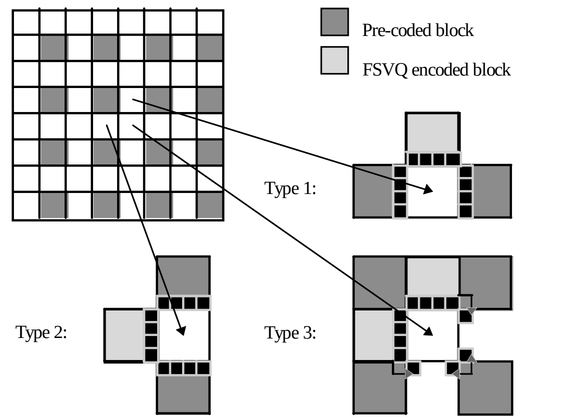

Figure 1. The pre-coded block arrangement and three prediction types for the three-sided side match VQ.

3. PROPOSED METHODS

The aim of this new side match design is two folds: (1) reduce the state codebook size as smallest as possible, it is better reduced to be 1 if the prediction can perform perfectly; (2) improve the prediction quality for edge blocks. The formal can reduce the bit rate and the latter can enhance the coding quality.

3.1 Three-Sided Side Match VQ

TSMVQ bears the overhead of pre-coded blocks by itself, however, the more accurate the side match prediction, the smaller the state codebook size it needed. We look forward to reducing the state codebook size as much as possible, even reducing to exact one codeword (the best-match codeword) to attain lower bit rate. For over 90% of non-edge blocks, in our experience, the best three-sided side match prediction blocks agree with the best blocks. Thus, in our design, we first partition the blocks into two categories: non-edge and edge. The state codebook size of a non-edge block is set as 1 and it is set as 64 for edge blocks. The blocks with state codebook of size 1 are denoted as *data-free* blocks.

Figure 2(a) depicts the encoder diagram of TSMVQ. In the beginning, the pre-coded vectors are encoded as VQ indices by ordinary VQ, and these indices are then transmitted to the TSMVQ decoder, shown in Figure 2(b). After that, the other (except pre-coded) input vectors are processed by an FSVQ mechanism with three-sided side match. The predictor, will perform two jobs, edge block recognition and state codebook construction. The pixel variance of side vector and an edge threshold are used to judge whether a block is edge or not. If the input block is recognized as non-edge, we resolve it to be a data-free block; otherwise, the side match predictor creates its own state codebook, then TSMVQ finds the best match state codeword and the corresponding index.

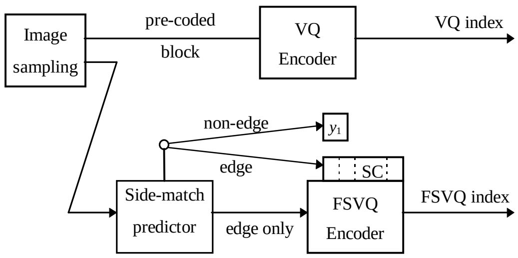

Figure 2(a) The encoder of the three-sided SMVQ.

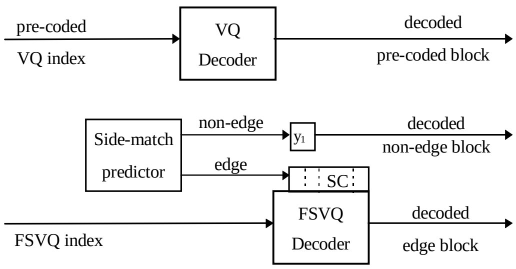

Figure 2(b). The decoder of TSMVQ.

Figure 2(b) depicts the decoder diagram of TSMVQ. All the received VQ indices of the pre-coded blocks are decoded into the corresponding codewords. As for the rest blocks, TSMVQ decoder finds the matched (state) codewords and fills them into the holes of the reconstructed image. Similar to the encoder, the (three-sided) side match predictor classifies the rest blocks into two classes, edge or non-edge, to decode them separately. For each hole in the reconstructed image, if it is recognized as non-edge, the encoder produces only one best-match codeword with minimal side match distortion. Otherwise, the hole is edge, a state codebook is formed by three-sided side match and the corresponding codeword is found by the receiving FSVQ index.

A primary feature of TSMVQ is that a large amount of FSVQ indices need not to be transmitted. Besides, the pre-coded blocks will regularly refresh the codeword in FSVQ coding, and thus alleviates the error propagation.

To further reduce the bit rate of VQ indices and FSVQ indices, we employ two lossless coding methods: index grouping algorithm and Huffman coding for them, respectively. Hsieh, Tsai and Lu [5] presented a so called index grouping algorithm which groups up the blocks with the same index to encode the group paths efficiently. Their method performs better than other lossless coding scheme on VQ indices. So, we apply this algorithm to the pre-coded blocks for reducing the bit rate of VQ indices. Due to the high adjacent pixel correlation of nature scene, the codewords on the top of state codebook have higher probabilities to be selected as the best match codeword. Thus, we design an entropy-based VLC for reducing the FSVQ indices.

3.2 Hierarchical Three-Sided SMVQ

In TSMVQ, the pre-coded blocks are coded by regular VQ, without extra prediction, thus, the bit rate will take up a large fraction of the total bit rate. In our experience, at total bit rate < 0.3 bpp, the resulting bit rate of them is over the half. Thus, TSMVQ may not be efficient at lower bit rate.

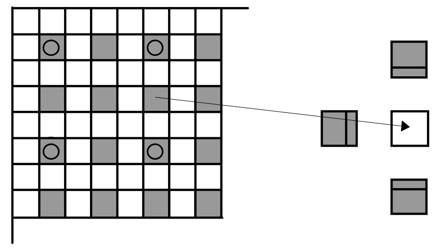

Figure 3. A hierarchical TSMVQ arrangement and one example for predicting a shade block by using three-sided side match.

We extend the prediction capability of three-sided side match to enhance its coding performance for low bit rate coding. The new one is called the hierarchical three-sided SMVQ (HTSMVQ) that an upper level of prediction is applied on the pre-coded blocks. Figure 3 depicts the arrangement of two-level hierarchical three-sided side match. In which, one-fourth part of shade blocks, the shade blocks marked as "o", are first coded by regular VQ, the rest shade blocks can be coded using three-sided side match then. Finally, the remaining blank blocks can be coded using three-sided side match again to complete a two-level three sided side match.

Consider Figure 3 again. Unlike the prediction in TSMVQ, the side information is not directed adjacent to the block to be predicted. So, the prediction of HTSMVQ will probably become poor in some blocks. In our implementation, see Figure 3, if a shade block is recognized as non-edge, then it will be coded with state codebook of size 1. Although the three side vectors are not direct adjacent to the current block, it is predicted as non-edge owing to the outer region is non-edge. Otherwise, if a shade block is recognized as edge block, it seems hard to predict, thus we let the state codebook to be the super codebook. That is, we regard such side information is useless in predicting edge blocks.

4. SIMULATION RESULTS

In our design, all the (super) codebooks were generated by the LBG algorithm. We conducted various simulations of TSMVQ on several 512×512 monochrome still images with 256 gray levels. The block size is 4×4, thus, there are 16384 vectors to be coded for an image. We first validated that TSMVQ is better than conventional SMVQ.

Table 1 lists the comparisons of PSNR values between conventional side-match FSVQ (SMVQ) and three-sided side-match VQ (TSMVQ) without entropy coding at the same bit rate 0.188 bpp. The results show that TSMVQ is better than conventional SMVQ and the improvement over SMVQ is ranging from 1.6 dB to 3.6 dB. The complete results of TSMVQ, after lossless coding, are also shown in Table 1.

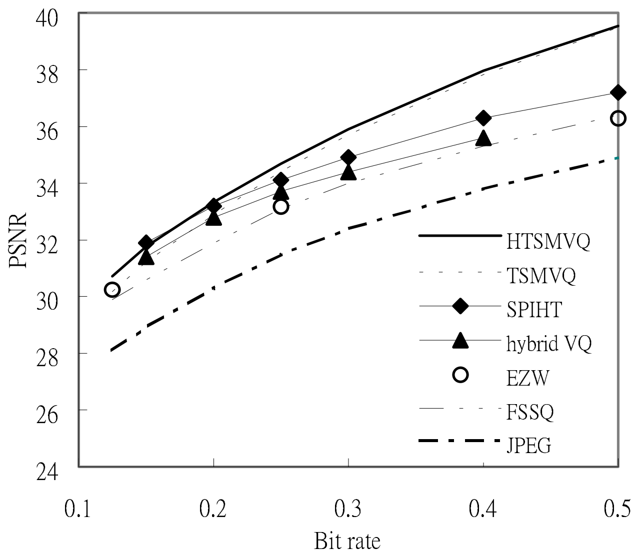

Figure 4. The comparisons of PSNR and bit rate among HTSMVQ, TSMVQ, EZW, SPIHT, FSSQ, hybrid VQ and JPEG for the test image "Lena."

For comparison, we collect several existing low bit rate coding results [6,7,8,9,10,4], two subband-based algorithms, three wavelet-based algorithms, one finite state VQ algorithm and JPEG. In [6], Naveen and Woods presented a finite state scalar quantization (FSSQ) that exploits the relationship between various subbands. Rinaldo and Calvagno [7] presented a hybrid VQ that exploits the redundancy of the multiresolution representation of image using subband coding. Wavelet-based coding is now the most effective scheme for achieving low bit rate for still image. Embedded zerotree wavelet (EZW) coding [8], proposed by Shapiro, is the pioneer. Said and Pearlman [9] also provided another embedded image codec, set partitioning in hierarchical trees (SPIHT), to further promote the performance of EZW. Wu and Chen [10] presented another improvement using a lossless algorithm called the context modeling for EZW symbols, the coding results are a little bit better than SPIHT.

Now, our HTSMVQ is compared to the existing low bit rate coding algorithms discussed as above. Figure 4 shows the resulting PSNRs versus the bit rates of seven methods, HTSMVQ, TSMVQ, SPIHT, hybrid VQ, EZW, FSSQ and JPEG, for the image "Lena." It is clear that our method, HTSMVQ, performs better than others in most of cases. In particular, its performance is the best at bit rate higher than 0.2 bpp. However, at bit rate lower than 0.15 bpp, SPIHT is still the best, our PSNR result drop about 0.14 dB.

5. CONCLUSIONS

In this study, we proposed a three-sided side match VQ that is an enhanced version of the conventional side match VQ. It is a simple but effective one that can compress still images to low bit rate. Before performing three-sided side match prediction, part of blocks must be transmitted to decoder. These pre-coded blocks will regularly refresh the codeword in FSVQ coding, thus they also contribute to the elimination of error (prediction error) propagation. To further reduce the bit rate, we extend the prediction capability of three-sided side match to accomplish a hierarchical version, HTSMVQ. According to the experimental results, HTSMVQ performs better than other existing low bit rate coding methods in most of the target bit rates. Notice that, our method is a pure VQ approach without employing any analysis tools, such as subband and wavelet using in SPIHT, hybrid VQ, EZW and FSSQ. Two more works are devoted in the future, the one is to advance the pre-coded bit rate reduction and the other is to extend HTSMVQ for coding image sequences. We hope this application can weigh against H.263.

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Table 1. The PSNRs (dB) of regular VQ, SMVQ and proposed TSMVQ without (w/o) and with lossless coding at the same bit rate 0.188 bpp.

	Lena	Peppers	Boat	Sailboat	Tiffany	Airplane
regular VQ	27.006	26.137	25.571	24.541	25.743	25.914
SMVQ	28.179	27.839	27.491	25.203	26.987	28.375
TSMVQ(w/o)	31.274	31.501	29.130	27.195	29.106	30.432
TSMVQ	32.532	32.508	30.817	28.209	29.849	31.994