A Wavelet VQ Image Compression System

*Jung-Chung Hsu, **Chaur-Heh Hsieh
Department of Information Engineering, I-Shou University,
Kaohsiung, 840, Taiwan, R.O.C
**peter_jch@kimo.com.tw, **hsieh@isu.edu.tw*

Abstract

The discrete wavelet transform (DWT) is a powerful technique for image compression because of its flexibility in representing image and its ability in adapting to the human visual system characteristics. This paper presents a new wavelet compression technique that mainly contains a modified search order coding (SOC) for lowest band and crossband vector quantization (VQ) for higher bands. For each lowest-band coefficient, a searching scheme is employed to find out the matched coefficient, within a tolerable distortion, from the previous coefficients, and then the corresponding search order of the matched coefficient is sent to the decoder. For higher bands, there exists correlation among the coefficients of different resolution levels (or scales). We employ a crossband vector quantization technique with a novel weighted distortion measure to exploit the correlation efficiently. The simulation results indicate that the new wavelet-based technique achieves good picture quality at very low bit rate.
Key word: wavelet, image compression, crossband, vector quantization (VQ), search order coding (SOC) and arithmetic coding.

1. Introduction

Recently, the discrete wavelet transform (DWT) has been widely studied for image compression because of its flexibility in representing images and its ability in adapting to the human visual system characteristics [1-7]. The quantization methods for wavelet-based image compression contain two types: scalar quantization (SQ) and vector quantization (VQ). In this paper, vector quantization is employed because it can obtain the optimal rate-distortion performance [8-9].

There are some problems in wavelet-based VQ systems such as (a) compression efficiency for lowest band is not high enough since the energy of the lowest band is often large, and (b) compression algorithms for higher bands are complicated. This paper attempts to develop a new wavelet-based VQ compression system to alleviate the problems. It consists of three main steps: DWT for the first step, modified search order coding (SOC) [10] and crossband VQ for the second step, and arithmetic coding for the last step. Simulation results reveal that the proposed algorithm achieves good quality of reconstructed picture at very low bit rate about 0.2 bits per pixel (bpp).

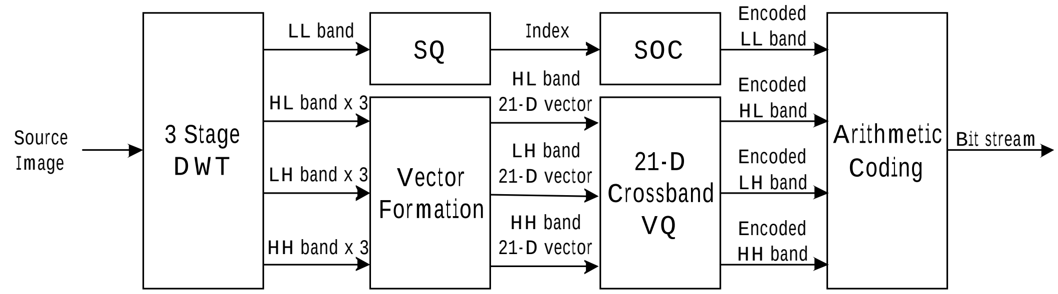
2. Proposed Wavelet VQ Compression System

2.1. System Overview

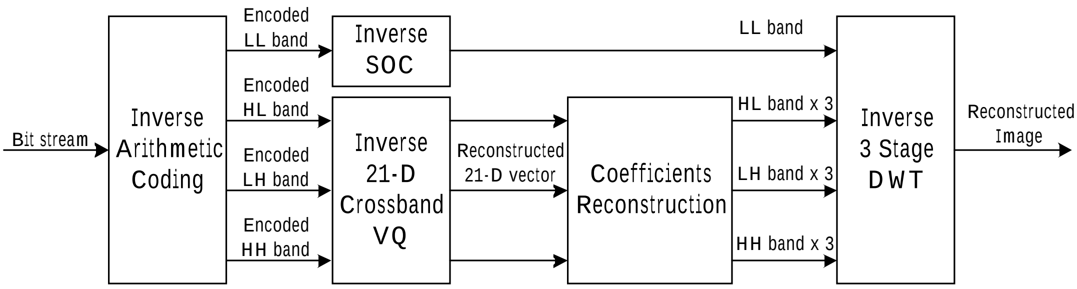
The block diagram of the proposed image compression system is shown in Fig. 1. The source image is decomposed into one lowest band (LL band) and three groups of higher bands (HL, LH and HH bands) using a 3-stage wavelet transform. The lowest band is quantized with 8-bit scalar quantizer and then encoded with a modified search order coding (SOC). The coefficient data in the same-orientation higher bands are formed into 21-dimensional (21-D) vector. The 21-D vector is quantized by a crossband vector quantizer. The symbols outputted from SOC and the crossband VQ will be encoded with arithmetic coding [12] to provide further compression. We design three arithmetic coders for SOC output and two arithmetic coders for 21-D VQ index.

2.2. Modified Search Order Coding for Lowest Band

The SOC is a method that uses the correlation among the vector-quantized indexes in a certain adjacent region to increase compression efficiency. It uses shorter search order information instead of the longer index for representing the input block [10]. The SOC is a lossless coding



(a) Encoder



(b) Decoder

Fig. 1. The block diagram of the proposed compression system

technique. In this work, we modify SOC for lossy coding of the quantized lowest-band coefficients. The quantization is performed with 8-bit uniform quantizer, thus the quantized coefficient index ranges from 0 to 255.

The search sequence of SOC is shown in Fig. 2. First, we assume that the block marked with **X** is the current coefficient index to be encoded. The sequence of search is in a clockwise manner. The first coefficient index to be searched is marked with A, then B, C, D, E, and so on. The coefficient index that has not been encoded (i.e. coefficient index with dashed-line in Fig. 2) is skipped in the search process. The searching process will continue until finding same coefficient index or the number of "miss-matched coefficient index" is greater than a maximum number *m*. If there is no index matched, then select the index with the minimum distortion from the *m* different indexes. If the minimum distortion is less than a predefined threshold T_{soc}, send flag bit “1” followed by SOC index *j* to decoder; otherwise, send flag bit “0” followed by coefficient index P_i to the decoder.

The SOC output symbols of the lowest band are encoded with arithmetic coding to further improve the compression efficiency. The SOC data consist of three types: (a) binary flag bits, (b) SOC index and (c) coefficient index. The binary flag is encoded by context-based arithmetic

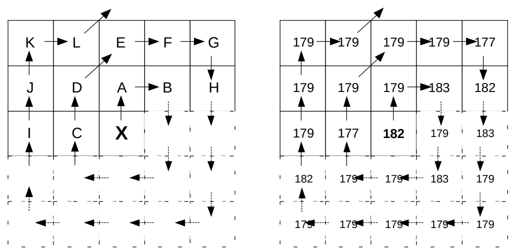


Fig. 2. Search sequence of SOC

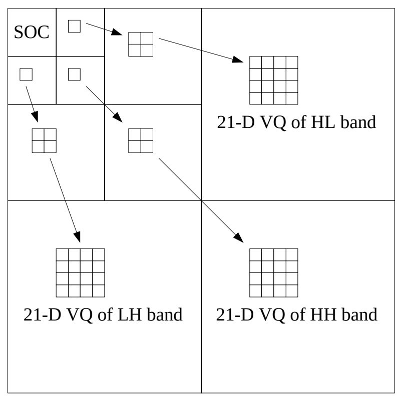


Fig. 3. Same orientation crossband vector

encoding (CAE) [11]. SOC index is encoded by adaptive arithmetic coding [12] with probability table containing *m* symbols. Coefficient index is encoded by adaptive arithmetic coding with 256 symbols.

2.3. Crossband Vectors Quantization

Vectors that are put into the VQ can be formed by coefficients from different subbands. In this work, a crossband vector is formed from C_i and its descendants, as shown in Fig. 3. We refer to this as a “same orientation” crossband vector. There are three types of 21-D vectors that are grouped together from three difficult orientations: HL, LH and HH bands, as shown in Fig. 3. The quantization process is described below.

In encoding, wavelet coefficients to be encoded are first divided into a set of non-overlapping vectors. Then the energy, E_i, of each input vector $C_i \in R^{21}$ is computed by

$$E_i = C_{i,0}^2 + \frac{1}{4}\sum_{j=1}^{j=4} C_{i,j}^2 + \frac{1}{16}\sum_{j=5}^{j=20} C_{i,j}^2 \qquad (1)$$

If E_i less than a predefined energy threshold T_e, send flag bit “1” to decoder. Otherwise C_i is mapped into an index k, which point to the closest (least distortion) codeword V_k in the codebook. The flag bit “0” is sent to the decoder followed by index k. It is noted that the energy measure defined in Eq. (1) is not uniform for all coefficients. Obviously, the coefficients in lower bands contribute more than those in higher bands. The definition is to consider the fact that the coefficients of lower bands are more significant than those of higher bands. We refer to the definition as weighted energy measure.

The most popular measure of distortion between two vectors is the squared Euclidean distance. In this paper, a weighted distortion measure for two vectors is proposed, which is defined as

$$d(C_i, V_k) = (C_{i,0} - V_{k,0})^2 + \frac{1}{4}\sum_{j=1}^{j=4}(C_{i,j} - V_{k,j})^2 + \frac{1}{16}\sum_{j=5}^{j=20}(C_{i,j} - V_{k,j})^2 \qquad (2)$$

The distortion measure gives larger weights to lower-frequency bands, whereas smaller weights to higher-frequency bands, which is similar to the definition in Eq. (1). The novel distortion measure procedure improves the rate-distortion performance significantly, as compared the squared Euclidean distance.

The crossband VQ outputs consist of (a) binary flag bits and (b) 21-D VQ index. The binary flag is encoded by context-based arithmetic encoding (CAE). VQ Index is encoded by adaptive arithmetic coding with probability table containing 256 symbols.

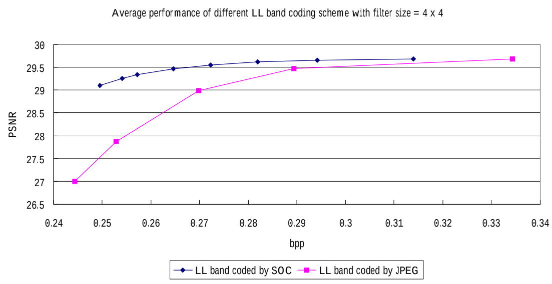


Fig. 4. Experimental results of lowest band coded by SOC and JPEG

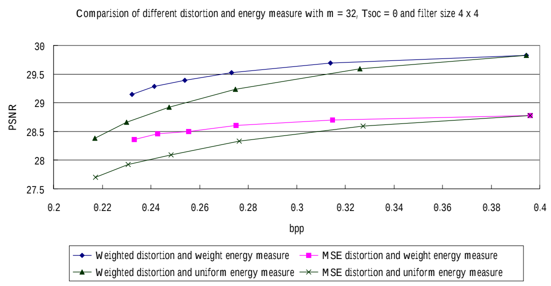


Fig. 5. Experimental results of general distortion and energy measure, weighted distortion and energy measure

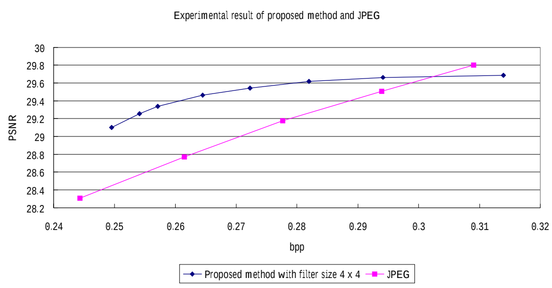


Fig. 6. Experimental results of proposed method and JPEG

3. Experimental Results

In this work, the bit rate is used to measure the compression efficiency; PSNR (peak signal-to-noise ratio) and reconstructed pictures are employed to evaluate the objective and subjective quality, respectively. We used a three-stage DWT with Daubechies filter. The filter size of 4 x 4 is chosen because it gives better subjective quality. The codebook with size N = 256 is obtained by LBG algorithm with random initialization [13]. The training set consists of wavelet coefficients of 20 monochrome images. The vector dimension is 21, and the weighted distortion measure, defined in Eq. (2), is used to generate the codebook. The test images include

Fig. 7. Reconstructed image of JPEG, bpp = 0.25, PSNR = 29.15dB

Fig. 8. Reconstructed image of the proposed method, bpp = 0.23, PSNR = 29.4dB

Fig. 9. Reconstructed image of Pepper with JPEG, bpp = 0.25, PSNR = 30.13dB

Fig. 10. Reconstructed image of Pepper with proposed method, bpp = 0.24, PSNR = 31.06dB.

Pepper, Lake (inside training) and Lena (outside training). The PSNR and bit rate listed in the following are the average of the three test images.

To demonstrate the efficiency of the modified SOC, we adopted MSOC and JPEG to code the lowest band, and higher bands are coded with the same crossband VQ. The result in Fig. 4 indicates that the modified SOC performs better than JPEG.

Fig. 5 shows the objective qualities of different distortion measure and energy measure. It is seen that the proposed weighted distortion measure and weighted energy measure achieves about 1 dB gain over the general distortion measure.

Fig. 6 compares the rate-distortion performances with the proposed method and JPEG. It is seen that the performance of the proposed method is better than JPEG. The comparison of subjective quality is demonstrated in Fig. 7 and Fig. 8. The results indicate that the proposed method yields less blocky effect at the lower bit rate.

Fig. 9-10 show the reconstructed Pepper image with the proposed method and JPEG, respectively. It is seen again that the proposed method provides better performance than the conventional JPEG.

4. Conclusions

In this paper, we have presented an efficient wavelet VQ technique for the compression of images. It employs several novel schemes including a modified SOC for coding the lowest band, a crossband VQ with weighted energy measure and weighted distortion measure for the quantization of higher bands, and several arithmetic coders for further coding the SOC outputs and VQ indexes. The results indicate that the proposed technique achieves better rate-distortion performance and visual quality than JPEG.

References

[1] A. S. Lewis and G. Knowles, "Image compression using the 2-D wavelet transform," *IEEE Trans. on Image Processing*, vol. 1, no. 2, pp. 244-250, Apr. 1992.

[2] H. Gharavi and A. Tabatabai, "Subband coding of monochrome and color image," *IEEE Trans. on Circuits and Syst.*, vol. 35, no. 2, pp. 207-214, Feb. 1988.

[3] N. Mohsenian and N. Nasrabadi, “Edge-based subband VQ techniques for images and video,” *IEEE Trans. on Circuit and Systems for Video Technolo.*, vol 4, no. 1, pp. 53-67, Feb. 1994.

[4] P. C. Cosman, R. M. Gary and M. Vetterli, "Vector quantization of image subbands: a survey," *IEEE Trans. on Image Processing*, vol. 5, no. 2, pp. 202-225, Feb. 1996.

[5] J. M. Shapiro, "Embedded image coding using zerotrees of wavelets coefficients," *IEEE Trans. on Signal Processing*, vol. 41, no. 12, pp. 3445-3462, Dec. 1993.

[6] A. Said and W. A. Pearlman, "A new, fast, and efficient image codec based on set partitioning in hierarchical trees," *IEEE Trans. on Circuit and Systems for Video Technolo.*, vol. 6, no. 3, pp. 243-250, June 1996.

[7] Y. Huh, J. J. Hwang, and K. R. Rao, "Classified wavelet transform coding of images using two-channel conjugate vector quantization," *in Proc. ICIP-94, Austin, TX*, vol. 3, pp. 363-367, Nov. 1994.

[8] R. M. Gray and A. Gersho, *Vector Quantization and Signal Compression*, Kluwer Academic Publishers, 1992.

[9] Y. Huh, J. J. Hwang, and K. R. Rao, "Block wavelet transform coding of images using classified vector quantization," *IEEE Trans. on Circuit and Systems for Video Technolo.*, vol. 5, no. 1, pp. 63-67, Feb. 1995.

[10] C. H. Hsieh and J. C. Tsai, "Lossless compression of VQ index with search-order coding," *IEEE Trans. on Image processing*, vol. 5, no. 11, pp. 1579-1582, Nov. 1996.

[11] N. Brady, F. Bossen and N. Murphy, "Context-based arithmetic encoding of 2D shape sequences," *IEEE Image Processing, 1997. Proceedings International Conference*, vol. 1 , 1997 , pp. 29-32.

[12] I. H. Witten, R. M. Neal, and I. G. Cleary, “Arithmetic coding for data compression,” Commun. ACM, vol. 30, pp. 520-540, June 1987.

[13] Y. Linde, A. Buzo, and R. M. Gray, "An algorithm for vector quantizer design," *IEEE Trans. Commun.*, vol. COM-28, pp. 84-95, Jan. 1980.