EMBEDDED IMAGE COMPRESSION USING A CLASSIFIED MULTISTAGE VQ IN WAVELET DOMAIN

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ABSTRACT

A wavelet based embedded image coding using a classified multistage vector quantization (VQ) system is proposed. The classified multistage VQ provides the partial ordering and successive approximation of wavelet coefficient vectors. Using a multiple context model along with a priori information of the vector quantization system, the method produces an optimized bitstream in a rate distortion sense. In addition, coding coefficient vectors rather than single coefficients not only takes advantage of the correlation among coefficients, but it also reduces the significance map overhead leading to the coding efficiency. Computer simulations indicate that the proposed scheme is effective and its performance is competitive with the state of the art image compression techniques.

1. INTRODUCTION

Embedded image coding which provides progressive image transmission by generating a bitstream roughly in order of importance has received significant attention in recent years. The encoder can cease at any time when some target bit rate (or stopping condition) is met. Also, the decoder can stop decoding at any point, generating an image that is the best representation so far with the decoded number of bits. Shapiro introduced embedded zerotree wavelet coding (EZW) and obtained both fully embedded bitstream and efficient compression performance by exploiting the inter-subband dependencies using zerotree coding and conditional entropy coding [1]. Said and Pearman enhanced EZW and suggested the set partitioning in hierarchical trees (SPIHT), which serves as a benchmark in image compression [2]. Taubman and Zakhor proposed the layered zero coding (LZC), which is an efficient zero coding strategy, by exploiting full spatial correlation using context conditional arithmetic coding [3]. Li and Lei proposed the rate-distortion optimized embedded coder (RDE), which achieves both optimum and embedment by coding the coefficients with decreased rate distortion slopes [4]. Tauman developed embedded block coding with optimized truncation (EBCOT) by combining fixed run-length coding with context conditioning and taking advantage of the fractional bit plane coding [5].

In this paper, we propose an embedded image coding using classified multistage VQ with rate-distortion optimization. Wavelet coefficients in high frequency subbands are grouped to form vectors, and these vectors are classified and scanned in terms of their norms. The significance map is entropy encoded based on contextual conditional models, taking advantage of both intra-subband and inter-subband dependencies to improve coding efficiency. Instead of using scalar quantization, as was used by the approaches mentioned earlier, the multistage VQ is applied to provide the successive refinement in order to produce an embedded bitstream. Motivated by the work in [4], the proposed scheme implements the significance identification and refinement based on a rate-distortion function so that the generated embedded bitstream is optimal at most truncation points.

2. CLASSIFIED MULTISTAGE VQ

To extend scalar quantization to vector quantization, adjacent wavelet coefficients can be grouped into vectors in certain ways [6]. These vectors are classified into different classes in terms of a sequence of monotonically decreasing thresholds T_i, i = 0, 1, …, n-1. For vector $\mathbf{c} = [c_1\ c_2\ \ldots c_k]^T$ in k-dimensional Euclidean space R^k, the l_2 norm, which is defined as $\|\mathbf{c}\|_2 = (\sum_{j=1}^{k} c_j^2)^{\frac{1}{2}}$, is used for vector classification. The corresponding hyperspace is partitioned into n disjoint regions,

$$R_i = \left\{\mathbf{c} \in \Re^k : T_i \le \|\mathbf{c}\|_2 < T_{i-1}\right\}.$$

It follows that

$$\Re^k = \bigcup_{i=0}^{n-1} R_i \ \text{ and } \ R_i \bigcap_{i \ne j} R_j = 0 .$$

A classified vector quantizer Q with n classes can be designed by generating its sub-codebook $C_i = (\mathbf{y}_1, \mathbf{y}_2, \ldots, \mathbf{y}_{N_i})$ from the training set containing the vectors in the region R_i which is associated with the half-open interval $[T_i\ T_{i-1})$. Therefore, each region, R_i, is partitioned further into N_i small cells S_m corresponding to N_i reproduction vectors of C_i. Thus, we have

$$C_i = \{\mathbf{y}_1, \mathbf{y}_2, \ldots, \mathbf{y}_{N_i}\},$$

and

$$R_i = \bigcup_{m=1}^{N_i} S_m ,$$

where $S_m = \{\mathbf{c} \in R_i : Q(\mathbf{c}) = \mathbf{y_m}\}$, $\mathbf{y_m} \in C_i$ for each codeword index $m \in \Im = \{1,2,...,N_i\}$, and $S_m \bigcap_{m \neq l} S_l = 0$. T_i serves as the criterion of the classifier, and $i \in \aleph = \{0,1,...,n-1\}$ is the class index. Further, each vector is refined by a multistage vector quantization of residual vectors with codebooks $\{K_0, K_1, ..., K_{n-1}\}$.

Successive approximation of vectors can be achieved by a multistage vector quantization scheme [7]. The input vector **c** is approximated by the first stage quantizer Q_0 with $\hat{\mathbf{c}}_0 = Q_0(\mathbf{c})$, which is actually one of the codewords of codebook K_0. The residual vector $\mathbf{e_0} = \mathbf{c} - \hat{\mathbf{c}}_0$ is approximated by the second stage Q_1 using the corresponding codebook K_1 with $\hat{\mathbf{e}}_0 = Q_1(\mathbf{e_0})$, so that $\hat{\mathbf{c}}_1 = \hat{\mathbf{c}}_0 + \hat{\mathbf{e}}_0$ is an improved approximation to **c**. In the same way, a further refinement to **c** can be obtained by applying the third quantizer Q_2 and so on until the expected approximation is met or all of the stages are exhausted. Therefore, the reproduction vector is the summation of the successive items formulated as $\hat{\mathbf{c}} = \hat{\mathbf{c}}_0 + \hat{\mathbf{e}}_0 + \hat{\mathbf{e}}_1 + \ldots$.

Importance ordering and successive refinement of vectors can be implemented by the combination of classified VQ and multistage VQ. The classified VQ and the multistage VQ are constructed jointly in the way that the classified VQ is designed first, and then the multistage VQ is obtained by concatenating the obtained n vector quantizers whose codebooks are the same as the sub-codebooks of the classified VQ. During the implementation, Vectors are scanned and the significance of each vector is determined according to the norm in terms of a set of decreasing thresholds. If a vector is significant with respect to a certain threshold value, it is quantized by the classified VQ with the corresponding codebook, and the index is sent following the significance flag. The significance test also serves as a classifier of the CVQ process. Once a vector is found to be significant and quantized, its residual vector will be tested and refined further in the following threshold passes after all the vectors are considered for the significance test. The significance map and VQ indices are entropy coded by adaptive arithmetic coding before being transmitted [8].

3. CODING ALGORITHM

The proposed classified multistage VQ system uses two separate sets of codebooks: classified VQ codebooks C_is and multistage VQ codebooks K_is. A schematic diagram of the proposed system is provided in Figure 1. First, wavelet vectors are classified into a finite number of classes using their norms and a series of thresholds. In general, the thresholds are selected as $T_i = T_{i-1}/2$ with $T_{-1} = \infty$ and T_0 being a predefined value. The classified VQ codebooks are trained based on these training sets. The obtained classified VQ is then applied to the wavelet vectors and the residual vectors are classified using the same thresholds as before to construct the training sets for multistage VQ. The multistage VQ is constructed based on these training sets starting with the first stage corresponding to the first residual class. Note that the vectors in each class are quantized further using the codebook of the corresponding stage, and the obtained residual vectors are classified and added to the training sets for the following stages. During the codebook training, the entropy of each codebook is also obtained and will be used in the estimation of the rate distortion slopes of vectors.

Wavelet coefficients are grouped to form vectors, and these vectors are scanned iteratively. In each scan, we consider a sorting pass and a refinement pass as in most of the embedded coding algorithms. During the sorting pass, the significance of each wavelet vector is tested with respect to a given criterion and the significance map is encoded. Once a vector becomes significant, it is marked and quantized by the classified vector quantization, and the resulting index is encoded. The residual vector is to be considered later. After the sorting pass, the refinement pass is applied to the residual vectors, in which each residual vector is successively approximated following a sequence of quantization steps.

The low frequency LL subband in a wavelet decomposition contains most of the energy but only accounts for a small portion of the image. Therefore, it is encoded separately and transmitted first from other subbands by rounding the coefficient to an integer and sending it directly in full precision. To provide an optimal encoding in a rate distortion sense, the coefficients in other high frequency subbands are grouped into vectors and scanned repeatedly in terms of a series of predefined decreasing threshold values of rate distortion slopes (defined as the R-D slope iteration) $\gamma_0 > \gamma_1 > \ldots > \gamma_s > \ldots$. For each R-D slope iteration γ_s, a series of thresholds of vector norms $T_0 > T_1 > \ldots > T_{n-1}$ (defined as the coding layer iteration) will be considered. During a certain R-D slope iteration *s*, the expected rate distortion slope of each vector is calculated, and the vector having a rate distortion slope greater than γ_s is encoded. If the calculated slope of a vector is less than γ_s, no further coding is needed for this vector as long as its context remains unchanged during this R-D slope iteration. The scanning is carried out from the highest level to the lowest level, in the order of LH, HL, HH within each level.

4. EXPERIMENTAL RESULTS

Computer simulations were carried out using a five-level dyadic wavelet decomposition with well-known Daubechies 9/7 filter banks and a symmetric boundary extension on images. Wavelet coefficients were grouped into a 2x2 matrix, and rearranged into four-dimensional vectors. The proposed classified multistage vector quantization system with nine coding layers was constructed using the training sets from eighteen natural images. In addition to the codebooks, the thresholds and the a priori probabilities of the codebooks used for the calculation of the rate distortion function were also obtained during the system design. The simulation results of test images, Lena and Barbara, which are not included in the training set of the codebooks, as well as those (Peppers, Airplane, and Baboon) in the training set, are presented in Table 1. These images are grayscale with size 512×512 pixels. Figure 2 shows the original image of Lena along with the reconstructed images by the proposed method at 0.25, and 0.125bpp, respectively.

5. CONCLUSIONS

An embedded coding scheme with rate distortion optimized vector quantization in the wavelet transform domain is presented. The proposed method uses a classified multistage vector quantization system to accomplish both the priority partitioning and the successive refinement of the coefficient vectors. To simplify the system design, the multistage vector quantization shares the same set of codebooks to carry out the successive refinement of the residual vectors from different classes. Simulation results indicate the proposed method is efficient with good performance results in comparison to other state of the art image compression techniques.

6. REFERENCES

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Table 1 Coding PSNR results (in dB) of the proposed scheme for test images

Bitrate (in bpp)	Lena	Barbara	Peppers	Airplane	Baboon
0.125	31.2177	25.2602	32.1362	30.6383	23.1859
0.25	34.1353	28.2502	34.7212	33.7159	24.6605
0.5	37.1400	31.7357	36.9062	36.8892	26.8961
1.0	40.1914	36.0399	39.5278	39.7573	30.3248

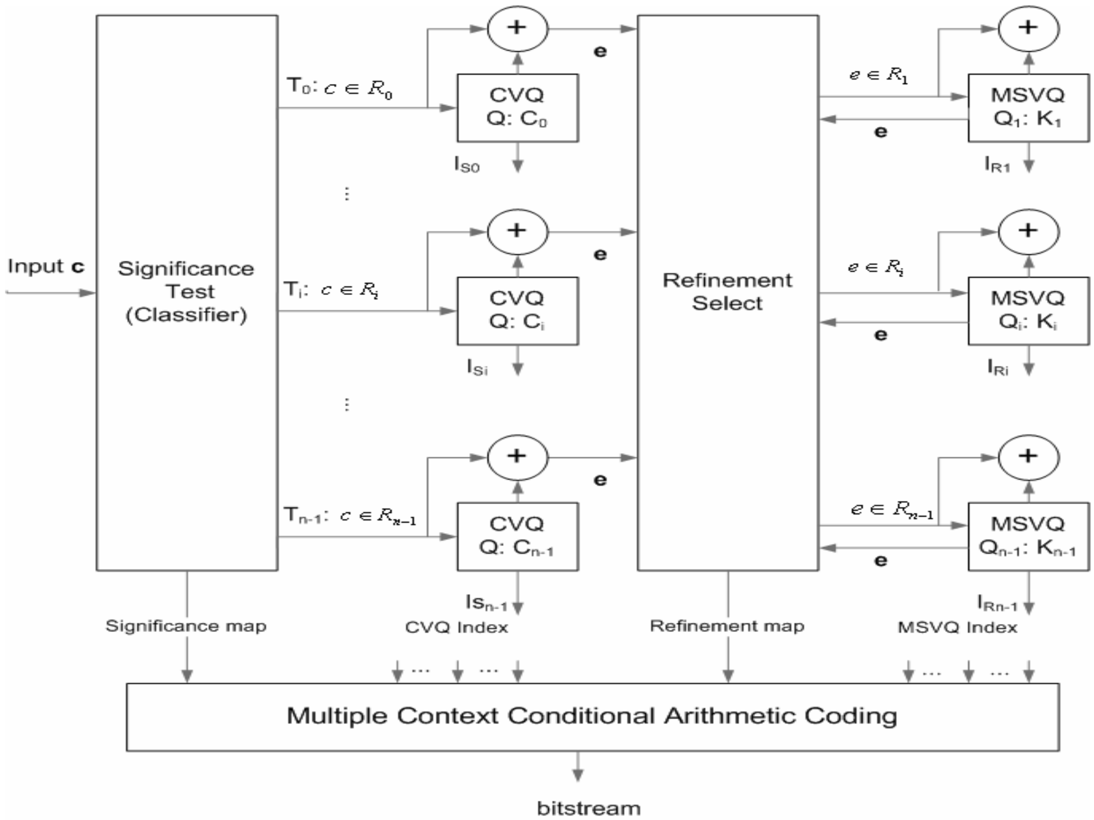

Fig. 1 Diagram of the proposed classified multistage vector quantization system

(a) (b) (c)

Fig. 2 Original and reconstructed Lena images: (a) Original image. (b) bitrate = 0.250 bpp, PSNR = 34.1353, (c) bitrate = 0.125 bpp, PSNR = 31.2177.