MULTISTAGE VECTOR QUANTIZATION OF IMAGE BY USING CLUSTERING INTERPOLATION IN DCT DOMAIN

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Abstract

An adaptive image coding scheme, called multistage vector quantization (MSVQ) is proposed. A new algorithm of MSVQ uses clustering interpolation in DCT domain and enables vector quantization of large image blocks with tolerable encoding complexity. Their mean luminance values are efficiently removed by the spline interpolative vector quantizer using a small number of bits. It can achieve a very high compression rate for low detailed images without complicated classification of transform blocks and subvector construction.

Keywords :

Vector quantization, clustering interpolation

1. Introduction

Vector quantization (VQ) [1] has become a popular and powerful data compression technique for speech and image coding. Although the performance of a vector quantizer approaches the theoretical upper bound as the vector dimension increases the complexity involved has made it impossible to use high-dimensionality VQ in practise. Due to the unstructured nature of the codebook generated by the LBG algorithm [2] the encoding complexity generally increases exponentially with rate (for a fixed dimension) or dimension (for a fixed rate). Several VQ techniques [3] have been proposed which mitigate the complexity barrier. Some examples are tree structured VQ, multistage VQ, shape-gain VQ, predictive VQ, transform VQ, interpolative VQ, hierarchical VQ. Nevertheless, all such techniques inevitably compromise the optimality of direct „full-search" VQ [4] and thus in some applications the complexity-distortion tradeoff of suboptimal VQ puts it at a disadvantage when compared with alternate heuristic coding methods. In this paper, we propose a new scheme of MSVQ for image coding, that enables VQ of large image blocks with tolerable encoding complexity and permits progressive image reconstruction. This scheme uses the concept of multistage VQ, transform VQ, and interpolative VQ.

2. Multistage vector quantization

MSVQ increases the quantization efficiency by converting widely spread amplitudes into very concentrated residual errors lying in a smaller range near the origin where they can be coded more efficiently. Fig.1 shows the block diagram of a 3-stage MSVQ. The objective of the first stage is to approximately remove the local structure of the input image. For this objective, we have implemented interpolative VQ by combining VQ_1 with digital decimation (DEC) and spline interpolation (SI) [5]. The input image is partitioned into a series of nonoverlapping rectangular blocks. A vector is formed by feature values which are extracted from the subblocks of each block. The feature vector is vector quantized using a codebook designed by the generalized Lloyd algorithm (often called the LBG algorithm). An approximation of the original image is reconstructed from the quantized feature vectors by SI with the optimum spline function S(t) [6], which is derived from the B-cubic spline function B(t) by linear combination and shifting as follows

$$S(t)=\frac{4}{3}B(t)-\frac{1}{6}\left[B(t+1)+B(t-1)\right] \qquad (1)$$

where

$$B(t)=\begin{cases}\frac{2}{3}-|t|^2+\frac{1}{2}|t|^3, & 0\le|t|\le1\\ \frac{4}{3}-2|t|+|t|^2-\frac{1}{6}|t|^3; & 1\le|t|\le2\\ 0; & |t|\ge2\end{cases}$$

Spline interpolative VQ exploits inter-block correlation and efficiently removes local mean luminance values using a small number of bits. As a result, it enables to avoid the use of ineffiecient scalar quantization of d.c.

coefficients in transform domain [7]at the later stage. The blocking effect is, however, significantly diminished using inter-block SI.

The residual image of the first stage is fed into the second stage where it will be coded using two-stage transform VQ. The discrete cosine transform (DCT) is chosen here because of its superior energy compaction property with moderate computational complexity. The DCT blocks are zonal sampled to select high energy zone in the transform domain and include it in the quantization process. Then VQ_2 of the zonal sampled feature vectors are carried out. In order to better exploit the widely variable energy of transform coefficients, improve the compression efficiency and provide a perceptually more consistent image quality over all areas of the decoded image, threshold is introduced at the third stage of our 3-stage MSVQ scheme. We have used the following adaptive strategy. If the squared sum S of residual errors of the second stage, remaining in each zonal sampled feature vector is greater than threshold value T, the error feature vector is coded with VQ_3. Otherwise the one is not coded at this stage. By changing T we can adjust the trade-off between bit-rate and the decoded image quality.

3. Clustering interpolation

The clustering interpolation (CI) [8] is more robust to quantization noise than the other interpolation techniques that perform explicit interpolation on quantized feature values. The main idea of CI is to use different codebooks at the encoder and decoder in such a way that an explicit interpolation operation at the decoder can be avoided. While the encoder uses a low-dimensional codebook of feature vectors, the decoder containes a higher-dimensional codebook of corresponding interpolated vectors. While other MSVQ schemes with interpolation employ feature vectors, representing decimated samples in our scheme they represent transform coefficients of the zonal sampled blocks. This is a salient difference between our scheme and other MSVQ systems.

As shown in Fig.1, clustering interpolation (CI_1) of the second stage is carried out using quantized feature vectors from VQ_2. The same process of CI_2 is repeated at the third stage by quantized feature vectors from VQ_2 and VQ_3. Only one of them is in activity in dependence on side-information. At the second stage the codebook C_1 for CI_1 is designed as follows. From v-dimensional input vectors **X** of DCT, k-dimensional (k<v) feature vectors **Y** are generated by using DCT and zonal sampling (ZS), which are used to design the codebook of VQ_2 using the LBG algorithm with the squared-error distortion measure. The training set of vectors **X** with $S \leq T$ is then partitioned by their quantized feature vectors $\tilde{\mathbf{Y}}$. The centroid of the vectors **X** in each partition becomes a codevector of C_1 for CI_1, i. e. , an interpolated version of the . codevector $\tilde{\mathbf{Y}}$ and is the conditional mean, given by

$$\tilde{\mathbf{X}} = E[\mathbf{X} | \mathbf{X} \in A_i] \tag{2}$$

where

$$A_i = \{\mathbf{x} : \tilde{\mathbf{Y}} = i\} \tag{3}$$

Note that each partition has both a k-dimensional codevector of VQ_2 and a corresponding v-dimensional codevector of CI_1. These two codevectors are identified by the same index. Analogously at the third stage the codebook C_2 of CI_2 is designed. The training set of vectors **X** with S>T is now partitioned by their both quantized feature vectors $\tilde{\mathbf{Y}}$ from VQ_2 and $\tilde{\mathbf{Z}}$ from VQ_3. The centroid of the vectors $\tilde{\mathbf{X}}$ in each partition becomes a codevector of C_2 for CI_2 and it is calculated by the conditional mean as follows

$$\tilde{\mathbf{X}}_{ij} = E[\mathbf{X} | \mathbf{X} \in A_{ij}] \tag{4}$$

where

$$A_{ij} = \{\mathbf{x} : \tilde{\mathbf{Y}} = i \text{ and } \tilde{\mathbf{Z}} = j\} \tag{5}$$

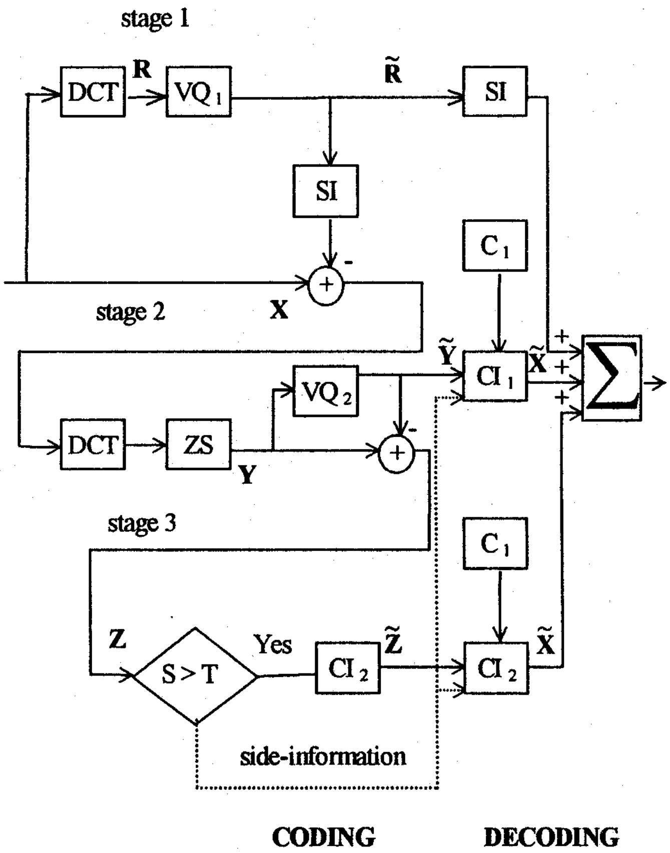

Fig.1 Block diagram of 3-stage MSVQ

4. Implementation and results

Computer simulations were carried out using the proposed MSVQ scheme to encode monochrome images of 512x512 pixels with 256 gray levels.

The input image is partitioned into a series of nonoverlapping square blocks of size 16x16 pixels, a typical size adopted in transform coders, to limit the inter-block redundancy. A feature vector of each block is formed by extracting sub-block means using the averaging operation over each sub-block of size 8x8 pixels, i. e., the decimation factor is 64. Each 4-dimensional feature vector **R** is encoded independently using 9 bit VQ_1. After all the feature vectors have been encoded, the inter-block SI is used over the encoded feature space. An error image is obtained by taking the difference between the original and encoded images, which will be encoded in the transform domain. The error image from the first stage is partitioned into 8x8 pixel blocks **X** and the DCT is performed over each block. Then zonal sampling gives feature vectors **Y** of 4x4 transform coefficients at the upper left coner of the DCT blocks of size 8x8. They are vector quantized using a codebook of VQ_2 containing 512 codevectors (9 bits) and only the residual feature vectors **Z** with S>2000 are

STAGE	bits/pixel	PSNR [dB]	
		MSVQ with CI	MSVQ without CI
1	0.04	21.89	21.89
2	0.18	26.33	25.26
3	0.25	31.16	26.71

Table 1: Overall bit-rates and PSNR values

encoded with 5 bit VQ_3. Clustering interpolation at the second and third stage is carried out by the related codebooks C_1 and C_2 of 8x8-dimensional codevectors.

We have tested the performance of the proposed MSVQ by encoding a popular image, known as "Lena". The test image was outside the training set used for codebook design. Objective performance was measured by the peak signal to noise ratio (PSNR). Table 1 lists the overal bit-rate and the PSNR value at each stage of MSVQ with CI and without CI. The original and reconstructed images for Lena at the third stage of MSVQ are given in Fig.2. The output of MSVQ with CI achieves very good quality and high PSNR value at 0.248 bits/pixel (bpp) and the improvement in its performance over that of MSVQ without CI is readily apparent. Achieved data compression of the coded image indicates increasing in comparison to the best prior work, i. e. MSVQ [9] based on classified transform coding, which achieves PSNR value 31.05 dB at the bit rate 0.302 bpp for the same original image. In addition the blocking effect in the coded image is better diminished by using the spline interpolation instead the linear one in that MSVQ.

a)

b)

c)

Fig. 2. Original and reconstructed images
a) Original image
b) Reconstructed image of MSVQ with CI at 0.248 bits/pixel
c) Reconstructed image of MSVQ without CI at 0.248 bit/pixel

5. Conclusion

In this paper, we have presented a new multistage VQ scheme with clustering interpolation (CI) suitable for low-rate image coding. The main feature of this scheme is the adaptive strategy of CI in DCT domain. The algorithm does not need complicated classification of transform blocks and subvector construction compared to the classified transform VQ. It employes different codebooks for coding and decoding of the proposed MSVQ, thereby avoiding the inverse DCT at the decoder. This work was supported by the national grant project G-9412 on Digital image coding with very low bit rate for videotelephones and multimedia terminals.

6. References

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