Image Compression using Zerotree and Multistage Vector Quantization

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Abstract

Embedded zerotree of wavelet coefficient (EZW) algorithm has become an effective way of compressing images. The use of multistage vector quantizer (MSVQ) provides successive-approximation coding for vectors. A new algorithm is proposed that provides good quality of reconstructed images at very low bit rates. The algorithm uses successive-approximation quantization of both scalars and vectors on wavelet coefficients of the image. Successive-approximation quantization of scalars and vectors is done using EZW and MSVQ algorithms respectively. EZW algorithm is applied to wavelet coefficients belonging to coarser level subbands and MSVQ is applied to vectors of wavelet coefficients belonging to finer level subbands. The proposed method further uses static Huffman coding to achieve more compression.

1 Introduction

Vector quantization (VQ) applied to wavelet transform/subband coding has been shown by many researchers to produce excellent quality images at low to high bit rates. Some of these methods apply VQ on each subband image independently as in [1] and other methods take into account interdependencies which exists between subbands of same orientation at different scales as in [4]-[5]. Here we propose a new coding approach for grey scale image compression using successive-approximation quantization of both scalars and vectors of the wavelet transformed image for progressive transmission purpose. Successive-approximation quantization of scalars is achieved using embedded zerotree of the wavelet (EZW) algorithm [2] and that for vectors is achieved using multistage vector quantization (MSVQ) [6]. EZW algorithm uses successive-approximation quantization of scalars together with an efficient scheme for predicting the absence of significant information across levels using self-similarity present in different subbands. The basic idea of MSVQ is to divide the encoding task into successive stages, where each stage refines the given input vector. As the wavelet transformed coefficients in coarser level subbands are more important than in finer level subbands, scalar quantization is applied to those coefficients belonging to coarser level subbands and MSVQ to blocks of finer level subbands.

In this paper we propose a new algorithm for coding wavelet coefficients using EZW algorithm and MSVQ. The proposed algorithm is constructed as an embedded coding so that the decoding process can be terminated at any point so as to achieve desired compression. The paper is organized as follows. Section 2 gives brief introduction to MSVQ. Section 3 describes the technique which uses zerotree structure along with MSVQ. Section 4 presents simulation results for test images "LENA" and "BOAT". Section 5 concludes the paper.

2 Multistage Vector Quantizer

The basic idea of multistage vector quantizer (MSVQ) [6] is to divide the encoding task into successive stages, where the first stage performs a relatively crude quantization of the input vector using a small codebook. Then, a second stage quantizer operates on the error vector between the original and quantized first stage output. The quantized error vector thereby provides a second approximation to the original input vector hence leading to a more accurate representation of the input vector. A third stage quantizer may then be used to quantize the second stage error vector to provide further refinement.

Codebook design for MSVQ can also be performed in stages. First, the original training set is used to generate the first stage codebook of desired size. Next, a new training set is generated of error vectors that represents the vectors applied to the second stage. This
training set is of same size as that of original and vector are of same dimension as the original. Such a design procedure is in sense greedy, i.e. each stage is optimized than optimizing all stages at a time. The codebook design complexity and memory requirements are reduced, but at the cost of decreased signal to noise ratio.

3 Subband Image Coding Using Zerotree and MSVQ

The proposed algorithm uses successive-approximation quantization of scalars and vectors using EZW and MSVQ algorithms respectively. EZW algorithm is an efficient scheme for predicting significant information across different levels, which tries to exploit the inherent self-similarity which exists between subbands of same orientations. EZW algorithm essentially uses zerotree structure along with successive-quantization of scalars. The fundamental idea of zerotree coding (ZTC) [2] is based on the prediction of insignificant coefficients across subbands. The zerotree coding approach is based on the hypothesis that if a wavelet coefficient at coarser scale is insignificant with respect to a given threshold \( T \), then all wavelet coefficients of same orientation at same spatial location at finer scales are likely to be insignificant with respect to \( T \). Given a threshold level \( T \), a coefficient \( x \) is said to be an element of a zerotree for threshold \( T \) if itself and all of its descendants are insignificant with respect to \( T \). An element of a zerotree is a zerotree root if its parent is not an element of a zerotree.

Figure 1 shows interdependencies in subbands at different levels. Threshold level \( T \) is taken as half of the modulus maximum value of wavelet coefficients except lowest level low-pass subimage.

The input image is transformed into 13 subbands by applying four levels of separable wavelet transform along rows and columns. The subband positioning is as shown in Figure 1. Subbands with suffix \( a, b \) and \( c \) represent horizontal, vertical and diagonal detail subimages respectively. Subimage \( 4d \) represents lowest level low-pass subimage of the input image. While encoding, the subbands are scanned starting with coarsest level subimages i.e. from \( 4th \) level in Figure 1. At each level subbands are scanned in order of \( a, b \) and \( c \). Before encoding the next level subbands, all previous level subimages must be encoded. In our scheme, zerotree starts from \( 4a, 4b \) and \( 4c \) instead of \( 4d \). The \( 4d \) subimage is scalar quantized with 8 bits per pixel (bpp).

In subband image decomposition, detail subimages \((a, b, c)\) corresponding to coarser levels have more energy compared to finer levels subimages. Hence, we apply scalar quantization to subimages of coarser levels and vector quantization to subimages of finer levels. Both scalar and vector quantization is done with successive approximation. With reference to Figure 1, the EZW algorithm is applied to \( 3rd \) and \( 4th \) level detail subimages and \( 1st \) and \( 2nd \) level detail subimages are vector quantized using MSVQ. 2 x 2 size blocks are chosen for \( 2nd \) level subimages and 4 x 4 size blocks for \( 1st \) level subimages. 1c subimage in Figure 1 is totally discarded while encoding because it has been found that human visual system (HVS) is not very sensitive to diagonal edges [1]. Four stage MSVQ is designed using LBG algorithm [3] and each stage has four codewords. The greedy algorithm is used for designing MSVQ. Output of the proposed algorithm is entropy coded to achieve higher compression.

The proposed algorithm is summarized below.

1. Given image is decomposed into four levels of the wavelet transform. Coarsest level subimage corresponding to \( 4d \) in Figure 1 is scalar quantized using 8 bits. Finest level high-pass subimage corresponding to 1c of Figure 1 is not encoded. Initial threshold level \( T \) is chosen as half of modulus of maximum value of subband images except \( 4d \) of Figure 1.

2. \( 3rd \) and \( 4th \) level coefficients are coded using EZW algorithm.

3. Wherever the \( 3rd \) level coefficient is not a zerotree root, the descendants of that coefficient, which are \( 2 x 2 \) block from \( 2nd \) level and \( 4 x 4 \) block form \( 1st \) level are vector quantized using MSVQ.

4. Output symbols from above steps are lossless coded using static Huffman codes.

5. \( T \) is made half and above two steps are repeated until desired bit rate is achieved.

4 Experimental Results

We present the encoding results for \( 512 x 512, 8 \) bit resolution LENA and BOAT images. We are using bi-orthogonal wavelets of [1] for decomposing the input image. Original images LENA and BOAT are shown in Figure 2 and 5 respectively. Reconstructed LENA image with PSNR of 30.59 dB was obtained at 0.25 bpp which is shown in Figure 3. When LENA image was encoded at 0.174 bpp we achieved PSNR of 29.28 dB, Figure 4. We see that our results compare very favorably with those reported in [5]. Also we see that, from visual perspective there is hardly any degradation in going from encoding at 0.25 bpp
to 0.174 bpp. The BOAT reconstructed at 0.25 bp gives 27.41 dB PSNR. Decrease in PSNR is obvious because this image has lot more details than LENA image.

5 Conclusion

The proposed algorithm for image compression using ZTC and MSVQ gives results which are comparable to that given in [5]. We observe that the penalty we are paying for using MSVQ is that of a marginally reduced PSNR for the encoded LENA image at the cost of reduced complexity and memory requirements of MSVQ. We believe that the algorithmic complexity of proposed scheme is much less than the one reported in [5]. Above all, the proposed scheme uses static Huffman coding where the same Huffman table is used for different images. This way overhead of sending Huffman tables along with coded data is eliminated. The results of the proposed scheme applied to different class of images are encouraging. We are planning to extend this scheme for low-bit rate video compression.

The technical report [7] contains many more simulation results to illustrate the efficiency of the proposed algorithm on different type of images.

References

[1] M. Antonini, M. Barlaud, D. Mathieu, and I. Daubechies, “Image Coding using Wavelet Trans-


