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A Zeroblock Coding Algorithm for Subband Image Compression

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ABSTRACT

The need for developing effective coding techniques for various multimedia services is increasing in order to meet the demand for image data. In this paper, a zeroblock coding algorithm is proposed for progressive transmission of images. The zeroblock coding algorithm is constructed as an embedded coding so that the encoding and decoding process can be terminated at any point and allowing reasonable image quality. Some features of zeroblock coding algirithm are 1) coding of subband images by prediction of the insignificance of blocks across subband levels, 2) a set of state transition rules for representing the significance map of blocks, and 3) block coding by vector quantization using a multiband codebook consisting of several subcodebooks dedicated for each subband at a given threshold.

Ⅰ. Introduction

In the last few years, subband coding has become one of the major technique for image compression. The subband coding concept was first introduced by Crochiere *et al.* [1] for the speech data compression. Since the application of two-dimensional subband coding to image compression by Woods and O'Neil [2], many research works have been reported for image coding [3]-[8]. The fundamental idea of subband coding is to divide the frequency band of the signal into a number of subbands using a bank of bandpass filters. In order to compress the image, subbands are then coded using some coding techniques. Basically, there are two approaches in the quantization of subband decomposed images: either quantization of each subband independently or quantization across subbands by exploiting dependencies between subbands. In the first approach, differential PCM [2], [3], transform coding [4], and vector quantization [5] have been used. A variety of approaches which explore the dependencies of subbands are reported using vector quantization [6], [7] and zerotree coding algorithm [8]. Zerotree coding scheme was developed in recognition of the difficulty in achieving efficient bit rate reduction for representing the significant coefficients via significance prediction.

A zeroblock coding algorithm is proposed in this paper for the coding of subband images. The proposed coding scheme is a generalized technique of the zerotree coding. The basic idea of the zeroblock coding algorithm is that subbands are divided into blocks and their significance is represented by a tree coding technique. A set of state transition rules are utilized for the significance map of blocks. Vector quantization is applied to the significant blocks using a multiband codebook. The encoder can terminate the coding process at any time whenever the desired target rate or distortion is achieved. This is possible since the bit stream is generated in an embedded fashion. This paper is organized as follows: Section 2 gives a brief overviews of subband coding and vector quantization. In section 3, zeroblock coding scheme is presented,

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and an image compression technique by combining the zeroblock coding and multiband vector quantization is described. Experimental results are discussed in section 4. The conclusions are summarized in section 5.

Ⅱ. Subband Coding and Vector Quantization

In order to decompose an one-dimensional signal into two subbands, a data is passed through a highpass filter and a lowpass filter to split up into two frequency bands. Output of these filters are then subsampled by a factor of two. This process of the reduction of the sampling rate is called decimation and the filter banks which divide signal is called analysis filter banks. In other to reconstruct original signal, the frequency bands produced by analysis filter banks are upsampled by a factor of two. This process of the increase of the sampling rate is called interpolation and the filter banks which merge frequency bands is called synthesis filter banks. All frequency bands with increased sampling rate are merged together to form a replica of the original signal. One-dimensional subband coding can be extended to image coding by a number of ways. One method is performed by applying one-dimensional subband coding to a image horizontally and vertically in separable ways. Another possible method is the use of two-dimensional nonseparable filters [9], [10]. Through subband decomposition, spatial spectrum of the input image is divided into four equal bands including one low frequency band(baseband) LL_1 and three high frequency bands HL_1, LH_1, and HH_1. Splitting of frequency band can be further applied to the baseband image. By applying subband decomposition to the baseband LL_1 in subband level 1, 7 subbands are produced : 4 subbands LL_2, HL_2, LH_2, and HH_2 in subband level 2 where LL_2 is the baseband of 2-level subband coding, and HL_1, LH_1, and HH_1 in subband level 1. Three level subband decomposition produces 10 subband images of three different scales. The resulting transformed coefficients are quantized in order to reduce the bit rate.

Vector quantization (VQ) [11] is a generalization of scalar quantization. VQ is a process in which data to be encoded are decomposed into k-dimensional blocks or vectors. In image coding, the original image is partitioned into blocks of size $k=p\times q$. Each vector $\boldsymbol{x}_i=(x_{i1}, x_{i2}, \cdots, x_{ik})$ is then compared with a collection of codevectors $\boldsymbol{y}_j=(y_{j1}, y_{j2}, \cdots, y_{jk})$ which is taken from codebook $\boldsymbol{Y}$ for the input vector $\boldsymbol{x}_i$ using a minimum distortion rule such that the error distortion of two vectors $\boldsymbol{x}_i$ and $\boldsymbol{y}_j$ is smaller than the error distortion with other codevectors $\boldsymbol{y}_l$, i.e., $d(\boldsymbol{x}_i, \boldsymbol{y}_j)\leq d(\boldsymbol{x}_i, \boldsymbol{y}_l)$ for all $l=1, 2, \cdots, N$ where N is the number of codevectors in the codebook $\boldsymbol{Y}$. The input vector $\boldsymbol{x}_i$ is represented by the index j of codevector $\boldsymbol{y}_j$ using $\log_2 N$ bits. The decoder has a codebook identical to the codebook in the encoder. The decoding process produces reproduction vectors $\boldsymbol{x}'_i$ by a duplication of codevectors $\boldsymbol{y}_j$ of index j with a table look-up procedure.

Ⅲ. Image Compression Using Zeroblock Coding

The zeroblock coding is a vectorized algorithm of zerotree coding [8] scheme. The fundamental idea of zerotree coding is based on the prediction of the insignificant coefficients across subbands. In the zeroblock coding algorithm, each subband is decomposed into blocks. To achieve a lower bit rate, dependencies within the subbands as well as among the subbands are explored in the zeroblock coding approach. Blocks are coded in order of the importance of the blocks to yield meaningful code at the beginning of the bit stream. The significance of each block is checked with respect to the threshold T_i for the iteration i for all the subband levels where $T_i=T_0, T_0/2, \cdots, 1$ and T_0 is the initial threshold. This iteration of scanning is continued until the target rate is met. If a block is significant with respect to the threshold T_i, quantization of the block is performed at the iteration I.

The scanning order of the blocks are important since the information about the location of current

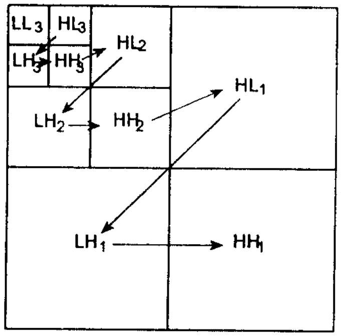

Fig. 1 Scanning order of the subbands for encoding the significance map of blocks.

scanning block can be implied in the scanning order. The scanning of blocks is performed by a zig-zag fashion such that, for an N-level subband system, the scan begins with the blocks in the HL_N subband followed by scanning the blocks in the subband LH_N and HH_N. The scanning is, then, move to other subbands in the next lower level with the same order until subbands in the lowest level HL_1, LH_1, and HH_1 are scanned. The scanning pattern is illustrated in Fig. 1. Since the scanning order is known to the encoder and decoder, the information about the location of the significant block is implied in the coding of significance of the block. As a result, bits send to the decoder are the bits needed to represent significance of blocks, and bits needed for quantization of the significant blocks.

A block is said to be significant block with respect to the given threshold T_i if the magnitude of any coefficients in the block is greater than or equal to T_i. If all coefficients in the block have magnitudes less than T_i, this block is said to be insignificant block. The significance map of blocks can be efficiently represented as a string of symbols with three-symbol alphabets: 1) zerotree root block, 2) isolated zeroblock, 3) significant block. Given a threshold T_i, a block is said to be an element of a zerotree if itself and all of its descendant blocks are insignificant with respect to T_i. A block which is an element of zerotree is said to be zerotree root block if it is not the descendant block of a previously found zerotree root block for threshold T_i. By coding the zerotree root block, coding of the descendants of zerotree root block is also accomplished inherently since descendants of the zerotree root block are also insignificant blocks. Isolated zeroblock is an insignificant block which has some significant blocks in its descendant blocks. If a block is significant block, this block is quantized by a vector quantization. In order to code significance map of blocks, the state transition rule is investigated instead of direct coding of the significance of blocks. The state of a block is defined based on the significance of a block with respect to the current threshold T_i and significance of a block with respect to the next threshold T_{i+1} if the significance of a block is zerotree root block or isolated zeroblock. Otherwise, the state of a block is defined based on the significance of a block with respect to the current threshold T_i.

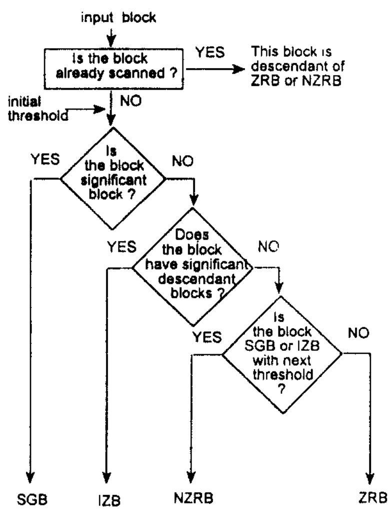

Fig. 2 The assignment of states of the blocks at the initial iteration.

We defined four states for the transition of significance of blocks as below:

1. SGB: a significant block with respect to the cur-

rent threshold T_i.

2. IZB : an insignificant block with respect to the current threshold T_i but one or more descendant blocks are significant blocks.
3. ZRB : a zerotree root block for the current threshold T_i, and it is also the zerotree root block with respect to the next threshold T_{i+1}.
4. NZRB : a zerotree root block for the current threshold T_i, but it will not be a zerotree root block for the next threshold T_{i+1}.

At the initial iteration with initial threshold T_0, initial state of each block is assigned by above definitions. This procedure of decision rules for the assignment of states of the blocks is illustrated in Fig. 2. Each state is then encoded by two bits such that ZRB is coded by '00', IZB by '01', NZRB by '10', and SGB by '11'. If a block is a descendant block of a ZRB, the state of this block is not coded since the state of this block can be implied in the coding of its zerotree root block. In the iteration i with threshold T_i, information of the state of a block is represented by state transition rules. The state transitions and bit assignments for the coding of these transitions are shown in Fig. 3.

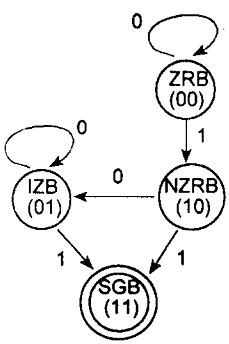

Fig. 3 State transitions and bit assignments

The scanning of blocks for the assignment of states is continued until all blocks are scanned with the scanning order. Before starting iteration i, blocks whose state are not SGB are marked as unscanned blocks. Blocks marked as unscanned block are scanned at the iteration i with threshold T_i, until all blocks are scanned. After scanning a block, the state of a block is assigned by state transition rules and state transition of the block is coded. If the new state of a block is SGB, coefficients of the block is quantized using multiband vector quantization following coding of state transition. Since all these states have two transitions for the next state we can code these state transitions using only one bit. For the coefficients in the lowest subband level, two symbols such as zeroblock and significant block are used since coefficients in the lowest level have no descendant blocks. The zeroblock coding algorithm with vector quantization is illustrated in Fig. 4.

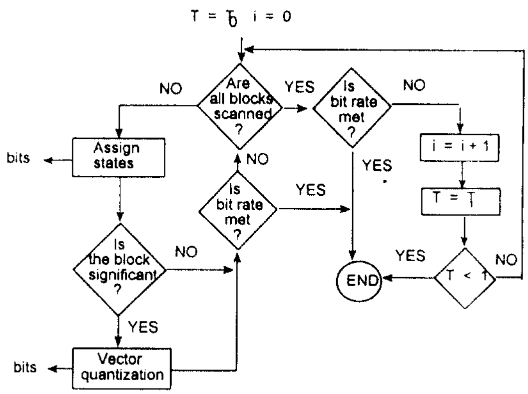

Fig. 4 The zeroblock coding algorithm

A dedicated vector quantizer is used for each subband to encode the significant blocks. The multiband codebook consists of many subcodebooks dedicated for each threshold and subband level. Total number of subcodebooks is $n_T \times n_L$ where n_T is the number of thresholds and nL is the number of levels. Since a threshold $T_i = T_{i-1}/2$, values of codevectors in subcodebooks for a threshold T_i is less than $T_{i-1}/2$ and greater than or equal to T_i. With this multiband codebook, we can reduce quantization errors between the original block and the reproduced block. Subcodebooks for each different threshold and level may have same codebook size and vector dimensions, or different codebook size and vector dimensions. A multiband codebook can be obtained by assembling all of these resulting subcodebooks.

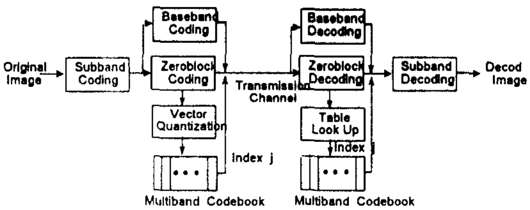

Fig. 5 Encoding/decoding system of the zeroblock coding scheme

Ⅳ. Experimental Results

The zeroblock coding algorithm was applied to the 512×512 8 bpp gray image 'Lena'. For the vector quantization, a 2×2 vector dimension is used for all of the thresholds and levels. The overall multiband codebook consists of 18 subcodebooks that are generated since 3-level subband systems are adopted and 6 threshold values are used. Initial threshold $T_0=32$ and then the thresholds $T_i=T_{i-1}/2$ are used. At the initial state assignment with T_0, the initial state of each block is assigned. After the first iteration with the initial threshold T_0, the state of each block is coded by the state transition rule. During the scanning, a flag indicating whether a block is already scanned or not is recorded for each iteration. Note that bits needed to code the state of each block is 2 bits for the initial threshold and 1 bit thereafter. The baseband image of size 64×64 pixels is sent directly without coding. The high frequency bands are coded using zeroblock coding system as shown in Fig. 5.

The performance of the proposed zeroblock coding algorithm was evaluated by the compression ratio and peak signal-to-noise ratio(PSNR). The resulting PSNR of the Lena image are 38.61 dB, 35.77 dB, and 31.46 dB for 1.0 bpp, 0.5 bpp, and 0.25 bpp, respectively. The original Lena image and reconstructed images at bit rates 8 bpp, 1.0 bpp, and 0.5 bpp are shown in Fig. 6, Fig. 7 and Fig. 8 respectively. These results are obtained without entropy coding of bit streams from zeroblock encoder. If entropy coding is applied to the bit streams, and the base band image is coded by proper compression techniques, the PNSR will be higher than these results.

Fig. 6 Original image.

Fig. 7 Quantized image at 1 bpp.

Ⅴ. Conclusion

In this paper, coding the high-frequency subband using the proposed zeroblock coding algorithm has been proven to be an effective image compression technique. The zeroblock algorithm is constructed as an embedded coding so that the coding process can be terminated at any bit rate and allow reasonable image quality. The advantage of this approach in practical applications are progressive image transmission based on embedded coding or layered image transmission for different service quality. The major contributions of our zeroblock coding system are: 1) block coding of subband images using the idea of zeroblock coding, 2) a set of state transition rules for representing the significant block map, and 3) a multiband codebook consisting of several subcodebook for each threshold and subband level.

Fig. 8 Quantized image at 0.5 bpp

References

1. R. E. Crochiere, S. A. Webber, and J. L. Flanagan, "Digital coding for speech in subbands," *Bell Syst. Tech. J.*, vol. 55, pp. 1069-1085, Oct. 1976.
2. J. W. Woods and S. D. O'Neil, "Subband coding of images," *IEEE Trans. Acoust., Speech, Signal Process.*, vol. ASSP-34, no. 5, pp. 1278-1288, Oct. 1986.
3. H. Gharavi and A. Tabatabai, "Sub-band coding of monochrome and color images," *IEEE Trans. Circuits Syst.*, vol. CAS-35, no. 2, pp. 207-214, Feb. 1988.
4. N. Tanabe and N. Farvardin, "Subband image coding using entropy-coded quantization over noisy channels," *IEEE J. Selected Areas Commun.*, vol. 10, no. 5, pp. 926-943, June 1992.
5. R. J. Safranek, K. MacKay, N. S. Jayant, and T. Kim, "Image coding based on selective quantization of the reconstruction noise in the dominant subband," in *Proc. IEEE ICASSP*, pp. 765-768, New York, NY, Apr. 1988.
6. P. H. Westerink, D. E. Boekee, J. Biemond, and J. W. Woods, "Subband coding of images using vector quantization," *IEEE Trans. Commun.*, vol. COM-36, no. 6, pp. 713-719, June 1988.
7. Y. H. Kim and J. W. Modestino, "Adaptive entropy coded subband coding of images," *IEEE Trans. Image Process.*, vol. 1, no. 1, pp. 31-48, Jan. 1992.
8. J. M. Shapiro, "Embedded image coding using zerotrees of wavelet coefficients," *IEEE Trans. Signal Process.*, vol. 41, no. 12, pp. 3445-3462, Dec. 1993.
9. M. Vetterli, "Multidimensional subband coding: Some theory and algorithms," *Signal Proc.*, vol. 6, pp. 97-112, Apr. 1984.
10. E. Viscito and J. P. Allebach, "The analysis and design of multiresolution FIR perfect reconstruction filter banks for arbitrary lattices," *IEEE Trans. Circuits and Systems*, vol. 38, no. 1, pp. 29-41, 1991.
11. N. M. Nasrabadi and R. A. King, "Image coding using vector quantization: a review," *IEEE Trans. Commun.*, vol. 36, no. 8, pp. 957-971, Aug. 1988.

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