EMBEDDED ZEROTREE BASED IMAGE CODING WITH LOW DECODING COMPLEXITY USING LINEAR AND MORPHOLOGICAL FILTER BANKS

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ABSTRACT

In this paper the problem of low bit rate image coding is addressed. The proposed approach is based on the embedded zerotree wavelet (EZW) algorithm. At high compression ratios, visually annoying artifacts appear in the reconstructed images using the originial EZW algorithm. Hence, the first goal of this paper is to improve the visual quality of the coded pictures. The main distortion is due to the Gibbs phenomenon of the linear filter bank and appears as "ringing effect" in the reconstructed images. The ringing effect is shown to be considerably reduced by using asymmetrical filter banks. It can even be completely removed by means of a morphological subband decomposition. The major drawback of the morphological filter bank is the loss of textures at high compression factors. The second objective is to make an optimal use of the embedded bit stream by reducing the computational cost of the decoding process. A new decomposition is proposed which reduces drastically the computational load of the synthesis stage.

1. INTRODUCTION

High compression image coding has triggered intensive interests in recent years. In this type of coding, visible distortions of the original image are accepted in order to obtain very high compression factors. High compression image coders can be split into three distinct groups. The first group is called waveform coding and consists of transform [1] and subband coding [2]. The second group called second-generation techniques consists of techiques attempting to describe an image in terms of contour and texture [3]. The third group consists of various methods belonging to none of the first two groups. Fractal coding [4] is an important technique in this group.

The proposed approach belongs to the first group. Two major types of distortions exist in the design of waveform image coders. The first one is called "blocking effect" and arises when block processing is performed. All the transform coders suffer from this distortion [1]. Unfortunately, the human eye is very sensitive to such a distortion and therefore, block coders are not appropriate at all for low bit rate image coding. The second type of distortion is due to the Gibbs phenomenon of linear filters and is called "ringing effect".

For high compression subband coding it is of major importance to exploit the existing zero-correlation across the subbands as proposed with the embedded zerotree wavelet (EZW) algorithm in [5]. This approach is based on four main blocks: 1) a hierarchical subband decomposition, 2) prediction of the absence of significant information across scales using zerotrees, 3) entropy-coded successive-approximation quantization, and 4) lossless source coding via adaptive arithmetic coding.

Improvements of the hierarchical subband decomposition are proposed with two distinct objectives. The first objective is to augment the quality of the reconstructed images such that the strong ringing effect introduced by the QMF filter bank is reduced. Morphological filter banks are further introduced to remove completely the ringing effect. The second objective is to reduce the computational complexity. A new decomposition is proposed which reduces the computational load of the synthesis stage. Note that it is a great advantage to have a low computational complexity of the synthesis stage in order to make an optimal use of the embedded bit stream.

2. EMBEDDED CODING

Using a successive-approximation quantization (SAQ) of the coefficients of the wavelet transform, it is possible to produce a fully embedded bit stream. This property finds many applications in practice such as progressive transmission, image browsing and multimedia applications. Notice that a standard subband decomposition followed by scalar quantization (SQ) does not pro-

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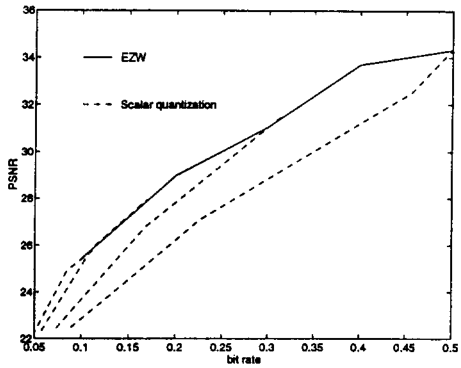

Figure 1: *Comparison of the progressive bit stream using the EZW algorithm and a standard subband decomposition.*

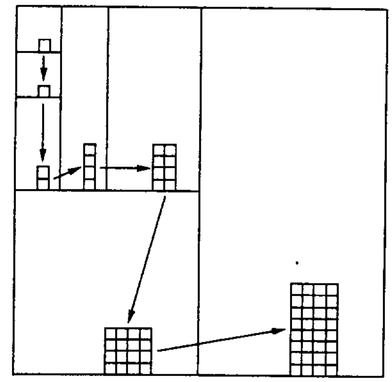

Figure 2: *Parent–Children relationship.*

duce an embedded bit stream. Although it is possible to do a progressive transmission of the data by ordering the subbands by their importance, the transmitted image at a lower bit rate (using fewer subbands) does not have the optimal bit allocation. Hence, it will have a poorer compression performance in the rate–distortion sense. This is shown in Fig. 1 which compares the progressive transmission of the subbands for four different quantizations steps with the approach of successive–aproximation quantization of the subbands.

3. SUBBAND DECOMPOSITION

The EZW algorithm uses a wavelet decomposition based on 9–tap QMF–filters [6]. The major artifact introduced by the quantization of the subbands is the ringing effect due to the Gibbs phenomenon. This artifact can be considerably reduced by choosing the appropriate filter bank. It is shown in this paper (see section 5) that the Asymmetrical Filter Banks (AFB) which have been shown to have a high coding gain [7] are appropriate for use in the EZW algorithm.

Although it is possible to reduce the ringing effect by an appropriate design of the subband filters using AFBs, it is not possible to find linear subband filters which do not have any ringing effect. To remove completely this artifact morphological subband decompositions (MSD) have been proposed [8, 9].

It is possible to incorporate the MSD in the EZW algorithm. The reconstructed images are then free of any ringing effect. Moreover, the decomposition has a very low computational load because of the special structure of the filter bank.

4. LOW DECODING COMPLEXITY (LDC)

In progressive image coding the computational complexity of the decoding part is much more important than the one of the coding part. In order to reduce the computational complexity at the synthesis stage of the filter bank a new hierarchical decomposition is proposed based on a novel parent–children relationship.

The principle is that each level of the decomposition splits the input image into two subbands. Then, only the lowpass subband is redecomposed into two more subbands. In order to choose adaptively the direction of the splitting the unified coding gain [10] can be used. Denote σ_{in}^2 the variance of the input image. The coding gain can be expressed as

$$G_{SBC} = \frac{\sigma_{in}^2}{\sqrt{\left(\sigma_1^2 \sum_{n=0}^{L_1-1} g_1^2[n]\right) \cdot \left(\sigma_2^2 \sum_{n=0}^{L_2-1} g_2^2[n]\right)}}$$

where σ_1^2, σ_2^2 are the variances of the subbands and $g_1[n]$, $g_2[n]$ are the impulse responses of the synthesis filters with lengths L_1 and L_2. This gain is computed for both directions, and the split is performed in the direction with the higher gain. The parent–children relationship for this decomposition is shown in Fig. 2. Note that the whole decomposition is described by one path and is not divided into three paths as for the standard wavelet transform. It is shown in section 5 that this simple decomposition is as efficient in terms of compression as the complete wavelet decomposition.

A comparison of the computational complexity of the synthesis stage is given in Table 1. It can be observed that the Morphological Subband Decomposition has a computational complexity ten times lower. Also, the EZW-LDC AFB reduces by more than a half the computational complexity compared to the full EZW algorithm in [5].

5. RESULTS

All results were obtained by coding and decoding an actual bit stream. In this way, the correctness of the

Algorithm	Multiplications	Relative Complexity
EZW–QMF 9	13.25 M	100%
EZW–AFB	9.275 M	70%
EZW LDC–AFB	6.965 M	52.5%
EZW LDC–MOR	0.995 M	7.5%

Table 1: *Computational complexity of the synthesis stage. LDC = Low Decoding Complexity. M = Multiplications per image pixel.*

algorithm is assured. In the EZW algorithm the input statistics of the symbol stream are changing very rapidly. Therefore, a specific adaptive statistical modeling is required. An exponential memory of the input data performs better than the block updating based on a maximum histogram count as used in [5]. This approach for the source coding part of the algorithm has been used for all following results.

Results of the proposed improvements are given in Fig. 3. The picture coded with the reference model JPEG is shown for comparison purposes. The blocking effect introduced by the JPEG algorithm is very annoying to the human observer and the mosquito noise around the high–contrast contours is also very visible. Even though the picture coded with the EZW algorithm does not suffer from any blocking effect, it shows a strong ringing distortion. This artifact is considerably reduced in the picture coded with the AFBs. Moreover, no visible difference is observed between the picture coded with the full EZW algorithm using the AFBs and the picture coded with the low decoding complexity using the AFBs. Finally, the picture coded using the morphological subband decomposition and the low decoding complexity is completely free of ringing effect. However, the drawback is the poor representation of the textures. Although a solution to this problem is given in [8] it can not be applied in a straightforward way to the EZW algorithm.

6. CONCLUSIONS

In this paper improvements of the embedded zerotree wavelet algorithm are proposed. They have two distinct objectives. The first objective is to improve the visual quality of the reconstructed images at low bit rates. The major visible artifact in this coding environment is the "ringing effect". It is shown in this paper that it is possible to reduce considerably this artifact by an appropriate design of the filter bank. The second objective is to reduce the computational cost of the decoding process. The proposed solution is based on an adaptive hierarchical decomposition. This decomposition is a two–band tree–structure which is in contrast to the usual four–band tree–structure. A new parent–children relationship is provided for this decomposition. This simple decomposition is as efficient in terms of compression as the complete wavelet decomposition. Moreover, using a morphological subband decomposition of this type allows to reduce drastically as well the computational cost as the ringing artifact in the reconstructed images.

7. REFERENCES

[1] ISO IEC JTC1 Commitee Draft, JPEG 8–R8. "Digital Compression and Coding of Continous–Tone Still Images". August 1990.

[2] J. Woods and S. O'Neil. "Subband coding of images". *IEEE Transactions on Acoustics, Speech, and Signal Processing*, pp. 1278–1288, October 1986.

[3] M. Kunt, M. Bénard, and R. Leonardi. "Recent Results in High–Compression Image Coding". *IEEE Transactions on Circuits and Systems*, Vol. CAS–34, No. 11, pp. 1306–1336, November 1987.

[4] Jacquin A.E. "Image Coding Based on a Fractal Theory of Iterated Contractive Image Transformations". *IEEE Transactions on Image Processing*, Vol. 1, pp. 18–30, January 1992.

[5] J. M. Shapiro. "Embedded Image Coding Using Zerotrees of Wavelet Coefficients". *IEEE Transactions on Signal Processing*, Vol. 41, No. 12, pp. 3445–3462, December 1993.

[6] E. H. Adelson, E. Simoncelli, and R. Hingorani. "Orthogonal Pyramid Transforms for Image Coding". Vol. 845, pp. 50–58, Cambridge, MA, October 1987.

[7] O. Egger and W. Li. "Subband Coding of Images Using Asymmetrical Filter Banks". to be published in *IEEE Transactions on Image Processing*, April 1995.

[8] O. Egger, W. Li, and M. Kunt. "High Compression Image Coding Using an Adaptive Morphological Subband Decomposition". *Proceedings of the IEEE*, Vol. 83, No. 2, February 1995.

[9] D. A. F. Florêncio and R. W. Schafer. "A Non–Expansive Pyramidal Morphological Image Coder". In *Proceedings of the International Conference on Image Processing*, Vol. II, pp. 331–335, Austin, TX, November 1994.

[10] Jiro Katto and Yasuhiko Yasuda. "Performance Evaluation of Subband Coding and Optimization of Its Filter Coefficients". *SPIE, Visual Communications and Image Processing*, Vol. 1605, pp. 95–106, 1991.

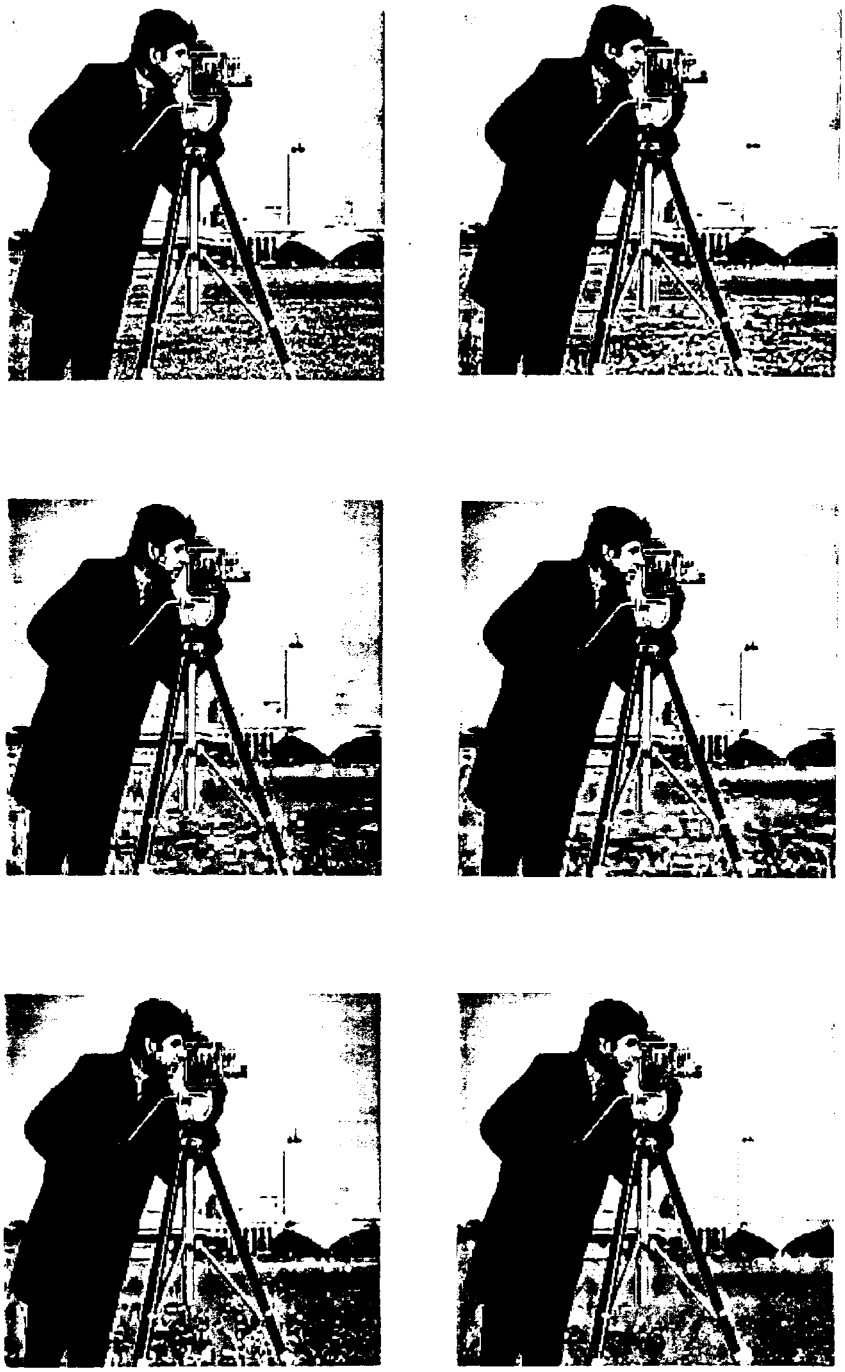

Figure 3:

(a)	*(b)*
(c)	*(d)*
(e)	*(f)*

"Camera Man" 256 × 256 picture coded at 0.47583 b/p.

(a) Original 256 × 256. (b) JPEG quality 5, 26.48 dB. (c) EZW–Algorithm, 27.97 dB. (d) EZW–Algorithm using AFB filters, 27.71 dB. (e) EZW–Algorithm with low decoding complexity using AFB filters, 27.60 dB. (f) EZW–Algorithm with low decoding complexity using the Morphological Subband Decomposition, 26.14 dB.