

A VERY EFFICIENT LOW-BIT-RATE SUBBAND IMAGE/VIDEO CODEC USING SHIFT-ONLY PR-QMF AND ZERO-ZONE LINEAR QUANTIZERS

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ABSTRACT

Subband coding has been successfully used for image and video applications. This paper emphasizes two design issues of a subband codec. Namely, the selection of the filterbank family and the width of zero-zones in zero-zone linear quantizers. It is shown that the shift only filters (Multiplierless PR-QMF) performs as good as other popular filterbank families. Finally, the significance of the quantizers' zero-zones in codec's rate-distortion performance is presented. It is found that the proposed efficient subband image/video codec performs comparable with the leading techniques like embedded zero-tree wavelet (EZW) coding scheme reported in the literature. We also incorporated this efficient subband codec into a motion compensated video coding algorithm. It is observed that the superior performance of zero-zone linear quantizers is also valid for subband video coding. The subjective performance of the proposed efficient codec in image and video coding are found consistent with the objective performance results obtained.

1. INTRODUCTION

Subband transform has been forwarded as an alternative to the Discrete Cosine Transform (DCT) for low bit rate image/video coding applications [1][2][3]. The recent research on wavelet transforms and their relationships with the filterbanks have generated significant activities in applications areas like image and video coding. An inherent multiresolution (scalability) property of subband transform is desirable for visual signal processing and coding. Although there have been several attempts in the past to promote a subband transform based image/video codec algorithm as an international compression standard, it is shown that DCT based efficient codecs were not significantly outperformed or comparable in performance. More recently, an embedded wavelet (subband) hierarchical image codec and its extensions were proposed with scalable (multiresolution) representation feature [4]. It was shown that they outperform the DCT-based image codecs reported in the literature. The main property of this algorithm is to keep record of zero-valued subband coefficients and their inter-band implications. This book keeping operation naturally requires an overhead budget from the available bit resources.

An efficient low-bit-rate subband image/video codec algorithm using shift-only PR-QMFs [5] and linear quantizers with a zero-zone is proposed in this paper[6]. It is shown

that the proposed algorithm provides a rate-distortion performance which is comparable, or marginally superior to, objectively and subjectively, the performance of embedded wavelet (subband) image codec reported in Ref. [4].

The main features of the proposed image codec algorithm are highlighted as the following :

- 1) **Shift only PR-QMFs:** These efficient filters are reported in Ref. [5] [7]. The coefficient values of these filters are only powers of two. Although this feature might not be very beneficial for software based image/video codecs, they are quite advantageous for the hardware implementations of real-time video codecs.
- 2) **Zero-zone linear quantizers:** The available compression bits are optimally distributed among subbands based on their variances. Except the lowest frequency band, all subband signals are quantized by employing linear quantizers with zero-zones. It is shown that the width of zero-zone is very crucial in the codec performance.

These features are summarized in the following sections. Then, rate-distortion performance of the proposed codec are presented for image and video coding. The remarks and the future research are found in the conclusion section.

2. SHIFT-ONLY PR-QMF

It is well recognized in the signal processing field that both the block transforms and filterbanks (wavelets) belong to the superset of generalized linear transforms (GLT). The main difference lies in the time and frequency properties of the functions in the transform set. Therefore, one can compromise on the frequency selectivity of functions over their time localizations. Filterbanks use longer duration time functions than the block transforms, e.g. discrete cosine transform (DCT), with their better frequency localization properties which naturally lead to the multiresolution representation (multirate) of signals.

The main disadvantage of filterbanks over block transforms is their computational complexity. A multiplierless PR-QMF family designed based on energy compaction measure was proposed in [5]. The filter coefficients of this family are constrained to be

$$h(n) = \pm 2^{\pm k_n}$$

or

$$h(n) = \pm 2^{\pm k_n} \pm 1 \quad n = 0, 1, \dots, 2N - 1$$

where $\{k_n\}$ are integers. Therefore, any filter coefficient is expressed as binary-shift or shift-and-add operation. We used an 8-tap shift only PR-QMF with its low-pass filter coefficients as shown in Table 1. It is shown in Ref.[5]

Table 1: Coefficients of 8-tap shift-only PR-QMF [5].

n	h(n)
0	-8
1	+8
2	+64
3	+64
4	+8
5	-8
6	+1
7	+1

that these filters have good time and frequency localizations. Their energy compaction performance are comparable with the known subband transform families. It is displayed later this paper that their performance in a subband image and video codec are also comparable to the others. Due to their computational efficiencies, they are more desirable to implement than the other filterbank families.

3. ZERO-ZONE LINEAR QUANTIZERS

It has been shown that the *zero-zone quantizers* bring performance improvements particularly in low-bit-rate coding applications [6][8]. The zero-zone quantizers used in this study are defined as the following:

- Define the *min* and *max* sample values of a band (dynamics)
- Optimally allocate the available bits among the subbands based on their variances $\{\sigma_i^2 \text{ for } i=1,2,3,\dots,10\}$ (e.g. *Band i* is assigned with an L^i -level linear quantizer. Then, define the step size of the linear quantizer i as $DELTA_i = (max - min)/L^i$)
- The *Zero - Zone* _{i} = $k \times DELTA_i$ of the quantizer is symmetrically placed around *zero*.

4. PROPOSED CODEC STRUCTURE AND PERFORMANCE

A 10-band, dyadic (octave-band) tree based subband image codec is designed. The subband variances are used for optimum bit allocation purposes. Linear quantizers with zero-zone are used. The distortion measure used is peak-to-peak signal to noise ratio (SNR_{pp}). The first order entropy is utilized as the measure of rate. It should be noted that the quantizer bins with zero-probabilities do not contribute in the calculation of this measure. In a practical entropy coder, there will also be some marginal price paid for the transmission of locations of zero-valued samples.

We focussed our attention on the following two points in this paper:

- (a) Selection of PR-QMF family: The coding performance of 10-Band dyadic subband transform based image codec is investigated for several different 8-tap PR-QMF families; e.g. shift-only, Daubechies wavelet filters (Binomial-QMF) and optimal PR-QMF, based on subband cross-correlations [3]. Fig.1 displays the rate-distortion performance of this image codec for 512x512 monochrome LENA image and the different filter families. It is assumed that the zero-zone of linear quantizer is equal to 3 times the quantizer step (DELTA) for each subband in these R-D curves. It is observed from these curves that the coding performance is quite insensitive to the filter families used. One should remember that all of these filters have quite good frequency selectivity property which is required for the multirate operations. Therefore, the proposed multiplierless PR-QMFs have significant advantages over the others due to their computational complexity.
- (b) The width of zero-zone in linear quantizers: Fig. 2 displays R-D curves of the 10-band image codec for the case of different zero-zone values. It is observed from these results that 3 times quantizer step (DELTA) yields the best performance for the image codec scenario tested in this paper.

Table 2 displays the rate-distortion results of the proposed efficient image codec along with the EZW image coding algorithm reported in Ref.[4] for the test image LENA (512x512, monochrome). This table shows that the proposed scheme has a comparable or marginally superior performance to the EZW algorithm. It is clear that the first is substantially more efficient to implement.

We utilized a block-based (8 pixels X 8 pixels) motion compensation for video coding experiments. Motion compensated frame difference (MCFD) signal is fed into the subband image codec described above. On the other hand, the block-motion vectors are coded lossless. Frame to frame motion is limited to be maximum ± 6 pixels per block. Each block is first decided if it is *moving* or *not-moving* based on some thresholding procedure. To arrive at this decision, each pixel is first checked to determine if it is a *moved* or *not-moved* pixel. If the number of *moved-pixels* is above a pre-set threshold in *moved-blocks*, then a brute-force search based motion estimation algorithm is utilized. The motion estimation step is skipped for *not-moved* blocks. The encoded version of the previous frame is used by the transmitter to synchronize it with the receiver end. Fifty frames of *Topgun* sequence are used for our experimental studies; 256x192 pixels/frame, monochrome. Fig. 3 and Fig. 4 display the distortion-distortion of this subband video codec as a function of frame index, respectively. The width of zero-zone in the linear quantizers is the parameter of these plots. Table 3 summarizes these rate-distortion plots. We used the multiplierless PR-QMFs in all these experiments. It is observed from these studies that zero-zone linear quantizers with $k = 2$ and $k = 3$ significantly outperform the cases

where no zero-zone and one-delta zero-zone quantizers are used. It is also observed that the zero-zone in the quantization step acts much like a noise-filtering operation. Note, that the image coders proposed based on wavelet minimas and maximas in the literature are similar to the zero-zone linear quantizer schemes presented in this paper.

Subjective performance of the experimental results are in accord with the objective performance obtained during this study.

Table 2: SNRpp performance for monochrome LENA 512x512 image

Rate	Shapiro [4]	Proposed
0.25 bpp	32.79	32.88
0.5 bpp	35.97	36.32
1 bpp	39.26	39.97 (0.995 bpp) 40.13 (1.022 bpp)

Table 3: Average R-D Performance for Topgun Sequence

	Rate (bpp)	D (SNRpp)
Zero-Zone=0	0.4653	31.64
Zero-Zone=1*DELTA	0.3391	35.12
Zero-Zone=2*DELTA	0.1424	37.19
Zero-Zone=3*DELTA	0.1242	36.48

5. REMARKS AND CONCLUSIONS

We can draw the following conclusions from this study;

- 1) The coding performance of zero-zone linear quantizer is shown to be superior to the conventional linear quantizer [6].
- 2) Shift-only PR-QMF provides objective and subjective performance which are comparable to the popular PR-QMFs in the literature.
- 3) The R-D performance of the proposed efficient subband image/video codec is comparable to the embedded wavelet (subband) hierarchical image codec proposed by Shapiro in [4]. (See Table 2)
- 4) Video coding performance comparisons show significant performance improvements for the case of zero-zone quantizers over conventional linear quantizers. It is also noted that the zero-zone performs as a noise filtering operation. The codec performance becomes quite robust. We observed this improvement subjectively as well.

The zero-zone quantizers have been known in the field for a number of years. More theoretical studies on these quantizers and their relationships with the interpolation filters of subband transforms are expected to be pursued in the future. We expect that the zero-zone quantizers will be incorporated in improved image codec algorithms. The future work is also expected to include the performance studies of

DCT-based image and video codecs using zero-zone linear quantizers and comparisons with the subband based codecs.

6. REFERENCES

- [1] J.W. Woods and S.D.O'Neil, "Subband Coding of Images," IEEE Trans. on Acoustic, Speech, and Signal Processing, Vol.34, pp.1278-1288, Oct. 1986.
- [2] H. Gharavi and A. Tabatabai, "Subband Coding of Quadrature Mirror Filtering," Proc. SPIE Visual Communications and Image Processing," pp. 51-61, 1986.
- [3] A.N. Akansu and M.S. Kadur, "Subband Coding of Video with Adaptive Vector Quantization," Proc. IEEE ICASSP, Albuquerque, New Mexico, pp.2109-2112, 1990.
- [4] J.M. Shapiro, "An Embedded Wavelet Hierarchical Image Codec," Proc. ICASSP, pp. IV 657-IV 660, 1992.
- [5] A.N. Akansu, "Multiplierless Suboptimal PR-QMF Design," Proc. SPIE Visual Communication and Image Processing, pp. 723-734, Nov. 1992 and US Patent Number: 5,420,891, 1995.
- [6] H. Brusewitz, "Quantization with Entropy Constraint and Bounds to the Rate Distortion Function," TRITA-TTT-8605, The Royal Inst. of Tech., Stockholm, Sweden, Dec. 1986.
- [7] A.N. Akansu, "Multiplierless PR-QMF for Subband Image Coding," IEEE Trans. on Image Processing, pp. 1359-1363, Sept. 1996.
- [8] B. Girod, F. Hartung, U. Horn, "Subband Image Coding," A Chapter in A.N. Akansu and M.J.T. Smith, Eds., Subband and Wavelet Transforms: Design and Applications. Kluwer, 1996.
- [9] A. Puri, H.M. Hang and D.L. Schilling, "An Efficient Block-Matching Algorithm for Motion-Compensated Coding," Proc. IEEE ICASSP, April 1987.
- [10] A.N. Netravali and J.D. Robbins, "Motion-Compensated Television Coding: Part I," Bell Syst. Tech. Journal, Vol. 58, pp. 631-670, March 1979.
- [11] P.H. Westerink, "Subband Coding of Images." Ph.D Thesis, Delft University, 1989.
- [12] J.W. Woods, Ed., Subband Image Coding. Kluwer, 1991.
- [13] R.L. Lagendijk, F. Bosveld and J. Biemond, "Subband Video Coding," A Chapter in A.N. Akansu and M.J.T. Smith, Eds., Subband and Wavelet Transforms: Design and Applications. Kluwer, 1996.
- [14] A. Said and W.A. Pearlman, "An Image Multiresolution Representation for Lossless and Lossy Compression," IEEE Trans. on Image Processing, pp. 1303-1310, Sept. 1996.
- [15] A.N. Akansu and R.A. Haddad, Multiresolution Signal Decomposition: Transforms, Subbands and Wavelets. Academic Press, 1992.
- [16] P.P. Vaidyanathan, Multirate Systems and Filter Banks. Prentice-Hall, 1993.

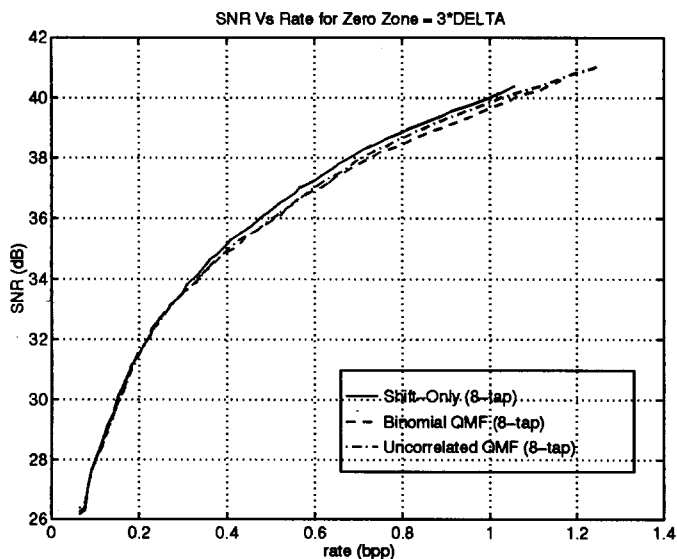


Figure 1: Rate - Distortion Performance Curves for different filter families with zero zone = $3 \cdot \Delta$.

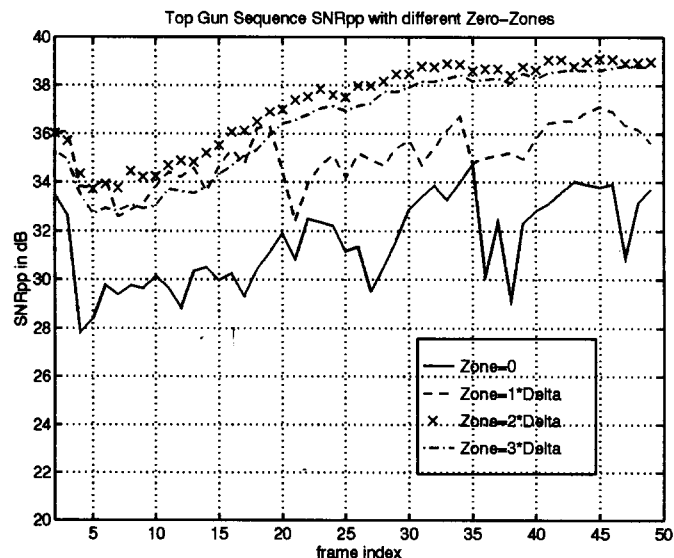


Figure 3: Top-Gun Sequence SNRpp Performance for Multiplierless PR-QMF Codec.

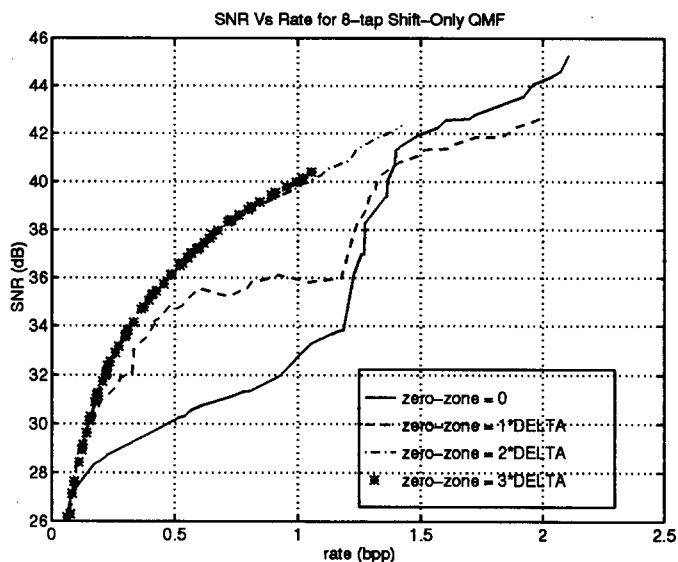


Figure 2: Rate - Distortion Performance Curve for Multiplierless PR-QMF Codec.

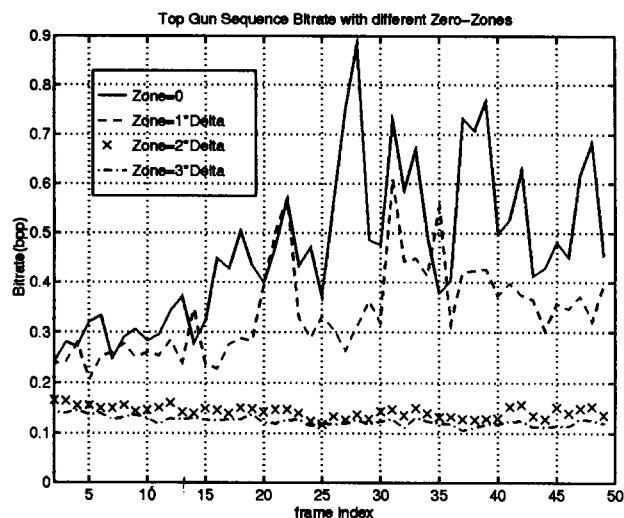


Figure 4: Top-Gun Sequence Bitrate (bpp) Performance for Multiplierless PR-QMF Codec.