A PERFORMANCE STUDY OF DCT AND SUBBAND IMAGE CODECS WITH ZERO-ZONE QUANTIZERS

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ABSTRACT

It has been shown in [1, 2] that zero-zone quantizers offer very good R-D tradeoffs, especially at low bit rates, in spite of their simplicity in implementation and concept. In [1] the performance of such codecs for still and moving images were reported for a dyadic 10-band subband coder. In this paper we extend those results to other subband image codecs, and DCT, and compare their performances.

1. INTRODUCTION

Subband transforms are fast emerging as an alternative to DCT due to their superior performance and non-blockiness, especially at low-bit rates. The main disadvantage of the former is of increased computational complexity. Though there exist alternatives for efficient implementation of subband transforms, like the shift-only PR-QMF family [3], they might not be very beneficial for software implementations.

In [1] it was shown that the performance of linear dead-zone quantizers used in conjunction with shift-only PR-QMFs is comparable to the state-of-the-art coders. In this paper we show that the performance is marginally improved by increasing the number of bands of the dyadic subband decomposition from 10 to 13 or 16. Surprisingly, DCT also is seen to outperform the 10-band dyadic decomposition. Best results are however obtained for uniform 64-band decomposition. For all decompositions the 8-tap shift-only PR-QMF [1, 3] has been used. As in the 10-band case it has been found that for all decompositions, the choice of dead-zone equal to three times the step size of the quantizer yields consistently best results. Prior to quantization, a recursive optimal bit-allocation strategy [4] depending on the variances of the bands, is employed to calculate the assignment of number of levels for the quantizer of each band.

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

Table 1: Coefficients of Shift-only PR-QMF

2. SHIFT-ONLY PR-QMF

The main disadvantage of filterbanks, or subband decomposition over block (fast) transforms is their computational complexity. A multiplierless PR-QMF family designed for best energy compaction was proposed in [3]. The filter coefficients of this family are constrained to be

$$h(n) = \pm 2^{\pm k_n} \tag{2.1}$$

or

$$h(n) = \pm 2^{\pm k_n} \pm 1 \tag{2.2}$$

where $\{k_n\}$ are integers. Therefore any filter coefficient is expressed as a binary-shift or a shift-and-add operation. In the performance evaluation we use the 8-tap shift-only PR-QMF with coefficients as shown in Table 1.

3. OPTIMAL BIT ALLOCATION

Let R_k be the rate assigned to each band, $k = 1 \cdots N$. Let σ_K^2 be the variance of each subband and σ_{qk}^2 the quantization error variance of the k^{th} band. From rate-distortion (R-D) theory [5],

$$\sigma_{qk}^2 = f(R_k)\sigma_k^2 \tag{3.3}$$

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where $f(R_k) = \gamma_k 2^{-2R_k}$ is the quantizer distortion function for unit variance input. γ_k depends on the pdf type of the k^{th} band. If R is the overall bit rate, then with the simplifying assumption that all bands have the same pdf, it can be shown that

$$R_k = R + \frac{1}{2}\log_2 \frac{\sigma_k^2}{(\prod_{i=0}^{N-1}\sigma_i^2)^{\frac{1}{N}}} \tag{3.4}$$

It can also be shown that the above algorithm makes the quantization error for each band to be equal ($\sigma_{q1} = \sigma_{q2} = \cdots = \sigma_{qN}$). For a given target rate the above equation may result in some R_k being zero or even negative. The interpretation of this is that the corresponding bands may be neglected as the variance of these bands are less than the targeted quantization error for each band. The next step is to recalculate R_ks, dropping the bands that are neglected (all coefficients of the neglected bands are made equal to zero). The procedure is repeated until no band is assigned zero nor negative bit rates. In practice this algorithm converges in 2 to 3 iterations.

It should be noted that the optimal bit-allocation algorithm is optimal only under the condition that all the bands have the same pdf types. The optimal bit allocation algorithm is then to be followed by an optimal (Lloyd-Max) quantizer to achieve the lowest quantization error for the given bit rate or the calculated bit allocation. It could be also be argued that as long as all the bands have the same pdf, then any consistent quantization scheme followed by entropy coding would be approximately optimal, (for a lower over-all bit rate than the target bit rate) depending on the quantization scheme used. Ignoring the above limitations for the time being, we apply zero-zone quantization to each band (except the lowest frequency or the dc band).

4. ZERO-ZONE QUANTIZERS

The zero-zone quantizer is simply a uniform quantizer with a difference that a few of the lower quantization levels (the dead-zone) are set to zero. For each band of variance σ_k the optimal bit allocation algorithm determines the number of quantizer levels, L_k. Depending on the dynamics of the band, the quantizer levels are chosen symmetrically around zero.

For example if $\min_k$ and $\max_k$ are the band dynamics, and $a_k = \max(\max_k, -\min_k)$, then we choose L_k uniform levels of length $\Delta_k = \frac{2a_k}{L_k}$ between $-a_k$ and $+a_k$.

We then define a dead-zone or zero-zone, equal to δ_k, where $\delta_k = \frac{n\Delta_k}{2}$. We call n as the number of zero-zones. All coefficients ranging between $-\delta_k$ and $+\delta_k$ are zipped to zero. The non-zero coefficients are quantized to the mid-point of the quantizer level they occupy.

5. PERFORMANCE EVALUATION OF THE CODECS

The R-D curves for the codecs employing DCT and 64-band uniform decomposition with shift-only PR-QMFs are shown in Figures 1 and 2 for n, the number of zero-zones equal to 0, 1, 2 and 3. Similar to the results obtained for the 10-band dyadic decomposition reported in [1] we see that for $n = 3$ we get the best R-D performance. It can also be seen that the smoothness of the R-D curves for $n = 3$ indicate that some sort of optimality has been reached. The unevenness of the plots for $n = 0$ and 1 clearly indicate lack of optimality.

Apparently, the use of zero-zone quantizer serves to equalize the pdfs of different subbands, thus making the bit-allocation strategy optimal. As explained in the previous section, similarity of the pdfs facilitate the use of a simple quantization scheme followed by entropy coding. Additionally, the zero-zones serve to remove the noise like components of corrupted images, and therefore the reconstructed images are visually pleasing. Reconstructed Lena images employing uniform 64-band decomposition at 0.26 bpp (34.1 dB PSNR) and 0.49 bpp (37.2 dB PSNR) are shown in Figures 3 and 4 respectively.

Figures 5, 6 and 7 display the performance of the zero-zone quantizers for three CCITT test images, Lena, Barbara and Goldhill. The R-D curves are shown for $n = 3$ for DCT, 10, 13 and 16-band dyadic subband decomposition, and for 64-band uniform subband decomposition. The uniform 64-band decomposition is seen to be the best for all the three images, and the 10-band dyadic subband decomposition, the most inferior. The performance of DCT based codec is superior to the 13-band dyadic decomposition and marginally inferior to the 16-band dyadic decomposition. Given the fact that DCT is the least computationally intensive of all the methods, it is felt that DCT is still a contender for future image compression standards.

6. CONCLUSIONS

In this paper we have evaluated the performance of different subband decompositions and DCT in conjunction with zero-zone quantizers. For all decompositions, it has been found that the recursive optimal bit allocation followed by zero-zone quantizers with dead-zone equal to three times the length of the quantizer level is practically optimal. It is also found that the uniform 64-band subband decomposition offers the best R-D performance. Surprisingly, DCT performs reasonably well and therefore might still be a contender for the image compression standards of the future.

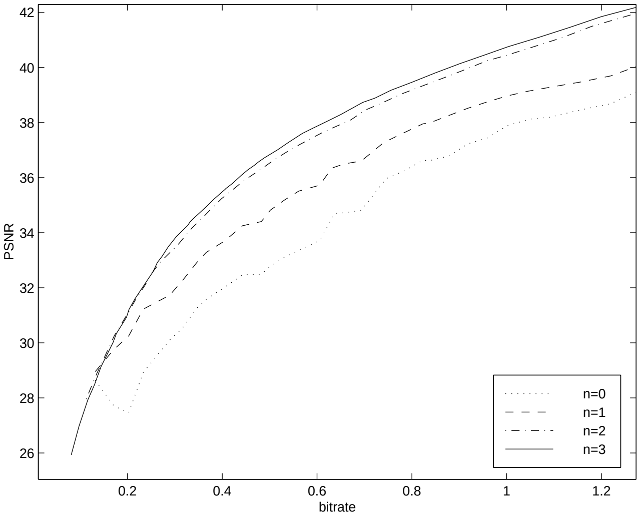

Figure 1: R-D Performance for Lena Image. DCT with Zero-Zones ($n =$) 0, 1, 2 and 3

7. REFERENCES

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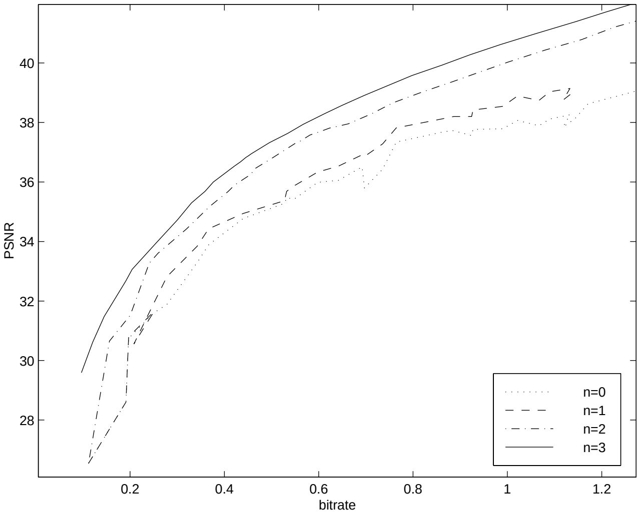

Figure 2: R-D Performance for Lena Image. 64-Band Subband Decomposition with Zero-Zones ($n =$) 0, 1, 2 and 3

Figure 3: Reconstructed Lena Image at .26 bpp. PSNR=34.1

Figure 4: Reconstructed Lena Image at .49 bpp. PSNR=37.2

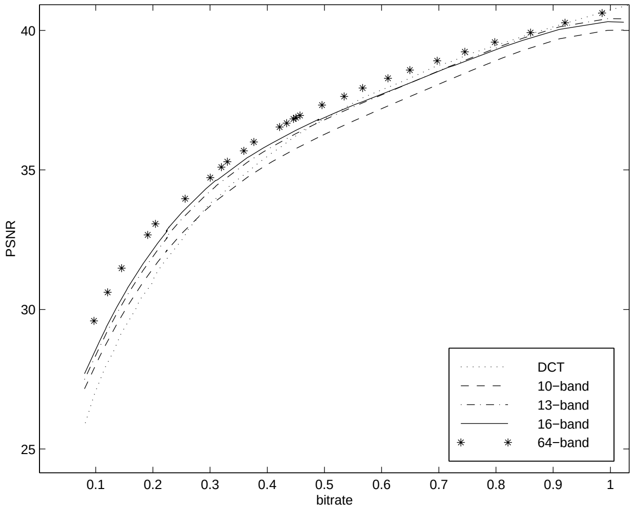

Figure 5: R-D Performance for Lena Image, $n = 3$, for DCT, 10-Band, 13-Band and 16-Band Dyadic Subband Decomposition and 64-Band Uniform Subband Decomposition

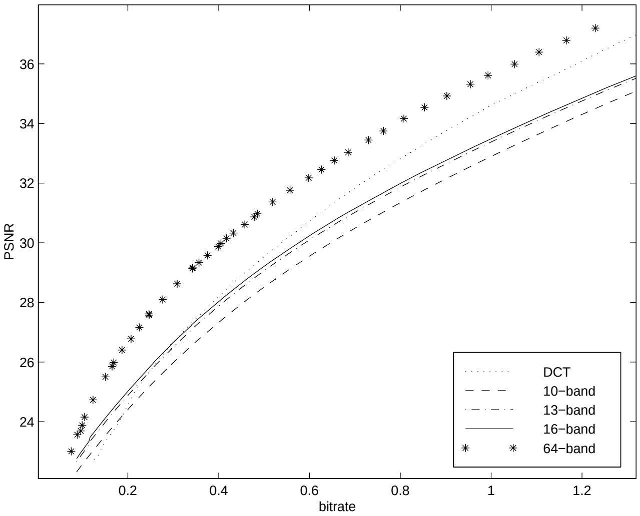

Figure 6: R-D Performance for Barbara Image, $n = 3$, for DCT, 10-Band, 13-Band and 16-Band Dyadic Subband Decomposition and 64-Band Uniform Subband Decomposition

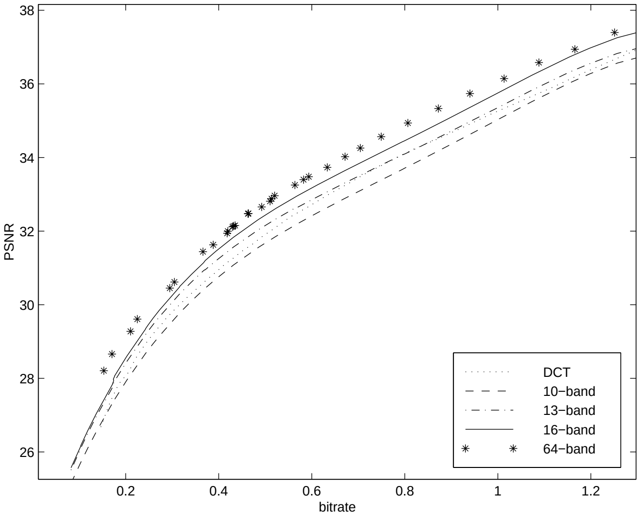

Figure 7: R-D Performance for Goldhill Image, $n = 3$, for DCT, 10-Band, 13-Band and 16-Band Dyadic Subband Decomposition and 64-Band Uniform Subband Decomposition