MODIFIED EZW CODING FOR THE M-BAND WAVELET TRANSFORM AND ITS APPLICATION TO IMAGE COMPRESSION

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ABSTRACT

This paper describes the extension of the embedded zero wavelet tree coding technique [2] to the M-Band wavelet transform. Through this scheme, we improve the efficiency of the embedded zero wavelet tree coding, that finds extensive application as a variable bit-rate coder. To prove the efficacy, we compare the compression ratio and the PSNR obtained by a traditional 2-Band wavelet based coder, with those obtained with the M-Band wavelet based EZW coder. One additional point discussed in this paper, is the performance of a traditional 2-level quantization in EZW against an M-Adaptive coder. We see the advantages and disadvantages in going in for an M-Adaptive coder and conclude based on the PSNR and Compression ratio obtained at various bit-rates. The variable bit-rate is emulated as multiple scans. Hence graphs plot the compression ratio or the PSNR against the number of scans. An important inference drawn from this paper is that, M-Band wavelet transform with M=Odd, exhibits special properties, as a result of which the EZW scheme performs much more efficiently with them.

1. INTRODUCTION

Wavelet based image coding schemes can provide flexible spatial, temporal, SNR and complexity scalability. Such schemes are generally used together with the Embedded Zero Wavelet Tree coding developed by Shapiro [2]. The EZW scheme provides for an embedded variable bit-rate coding technique with excellent compression and PSNR advantages at low-bit rates. The EZW scheme has been predominantly used with 2-Band wavelet transforms. The M-Band wavelet transforms are more efficient in signal decomposition than traditional wavelet transforms in general. The zero wavelet tree propagation varies with M for such an M-Band wavelet transform. This M-Band EZW coding provides for a more efficient variable bit-rate coding than the traditional EZW coding scheme. The following sections provide a brief insight into the M-Band wavelet transform and the EZW scheme; extend the EZW scheme to the M-Band wavelet transform and present the compression and PSNR graphs for a 2-Level and an M-Adaptive quantization scheme. The computational complexity involved and any special conclusion drawn are also presented.

2. THE M-BAND WAVELET TRANSFORM

Wavelet transforms [1], [3], [4] provide for a multi-resolution decomposition of a signal along orthogonal or bi-orthogonal bases. The multi-resolution representation distinguishes wavelet transforms from traditional block transforms like the Discrete Cosine Transform (DCT).

The M-Band wavelet transform [7], is realizable as a constant-Q M-band filter bank [5], [6], [8]. For M=3, we have a bank of 3 filters corresponding to a low-pass filter, a band-pass filter and a high-pass filter. A general M-Band Wavelet Transform is realized as per Fig. 1 below. The M-Band wavelet transform was implemented using cosine modulated filter banks.

M-Band wavelets (M>2) offer advantages in terms of Compact Support, Orthogonality, Linearity of Phase, Regularity and Interpolation over 2-Band wavelets. Hence they are very likely to be more effective than conventional 2-Band wavelets for image compression.

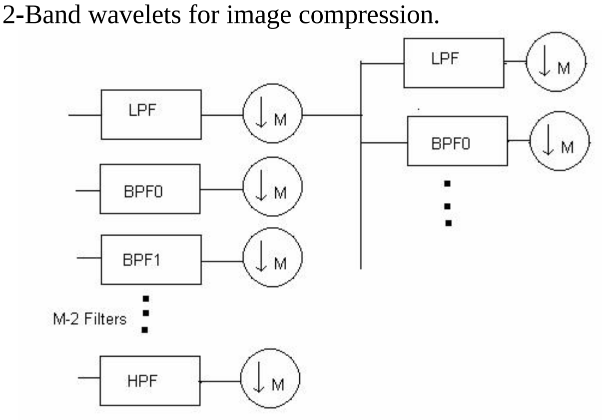


Fig 1. M Band Wavelet Transform Realization using constant Q Filters.

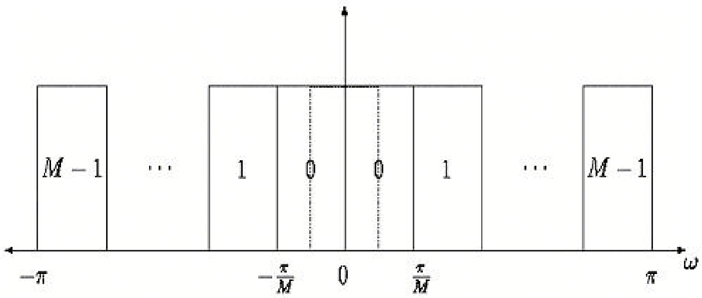


Fig 2. The M-Band wavelet transform filter bank

3. EMBEDDED ZERO WAVELET TREE CODING ADAPTED TO THE M-BAND WAVELET TRANSFORM

The embedded zero-wavelet tree coding scheme proposed by Shapiro [2] exploits the propagation of zeros leading to Zero-Trees that can be very effectively coded. It also provides for a variable bit-rate coding by providing for a range of compression gains and PSNR controllability. The traditional EZW coding scheme exploits the propagation of zeroes as $2^L x 2^L$ blocks, where L is the resolution level. For example, the zero tree starts as a point (the zero root) and at first level, we have a 2x2 region as the child, a 4x4 region as child at second level and so on.

With the M-Band wavelet transform, the propagation no longer occurs as $2^L x 2^L$ blocks, but as M^L x M^L blocks. Thus we'd have an M-Adaptive zero tree propagation scheme. This provides for larger and larger blocks of zeros to be coded more efficiently and hence provides for a greater compression ratio. Figures 3 and 4 below, describe the traditional and the adapted EZW scheme for M=3.

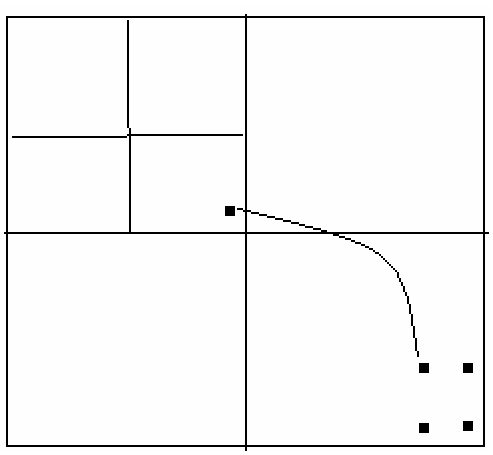


Fig 3. Zero tree propagation in 2-Band wavelet transform

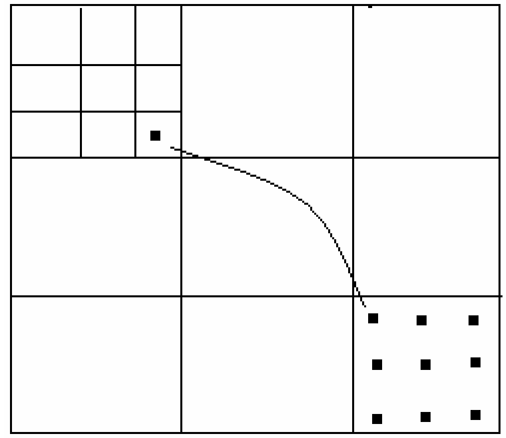
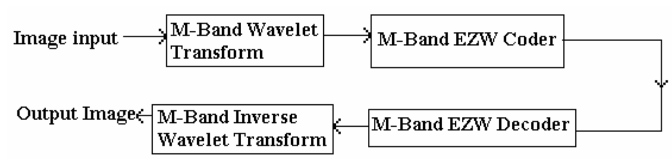


Fig 4.Zero tree propagation in 3-Band wavelet transforms

While the traditional EZW scheme uses 2-level quantization, the possibility of an M-Adaptive scheme exists. Such a scheme was implemented and the performance results are presented and discussed. This scheme uses threshold reduction in powers of M as against powers of 2 used in the traditional EZW scheme.

4. METHODOLOGY

The block diagram in figure 5 below describes the process that was implemented. All blocks were implemented in C. An M-Band wavelet library was implemented and used for the wavelet transform. The wavelet transformed data was encoded using the modified EZW encoder, also implemented in C. The implementation of the M-Band parent to child jump was notably tough. After the coding, the image was decoded



as well for PSNR calculation. The compression ratio was computed as well. Both the above computations were done after varying number of scans emulating a variable bit-rate environment.

Fig 5. General flow diagram

5. RESULTS AND INFERENCES

This section provides the PSNR and compression results obtained across number of scans for the M-Band EZW Coding (M>2) and the traditional EZW coding. The graphs are interpreted and inferences drawn are reasoned out.

5.1. Binary Quantization Results

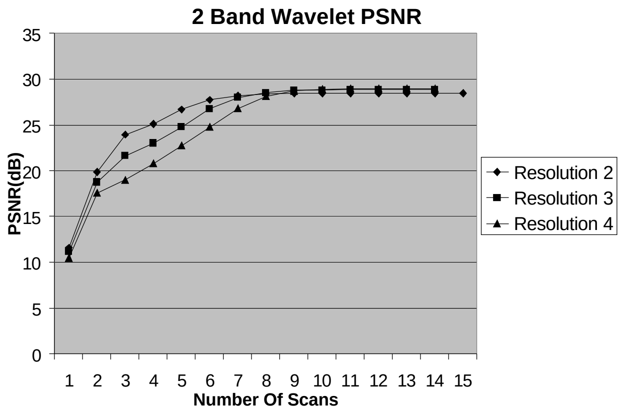


Fig 6. 2-Band EZW PSNR across scans

We see that as the decomposition level increases (resolution levels), the peak PSNR increases. This fact is further confirmed by the 3-Band wavelet PSNR chart below (Fig. 7).

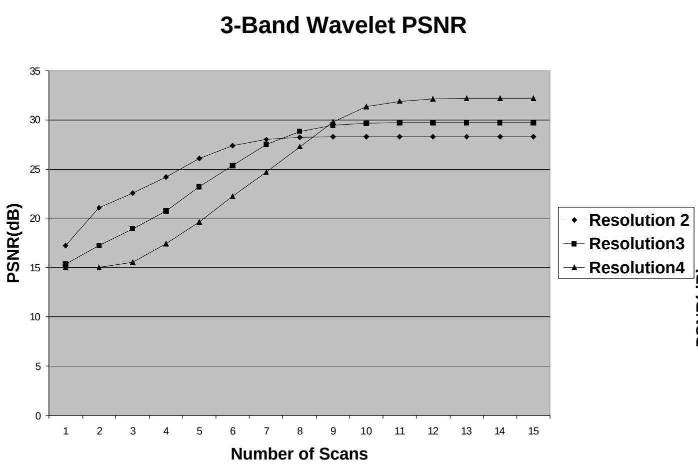


Fig 7. 3-Band EZW PSNR across scans

Figures 8 and 9 below present the compression ratio Vs number of scans for the 2-Band and the 3-Band EZW scheme.

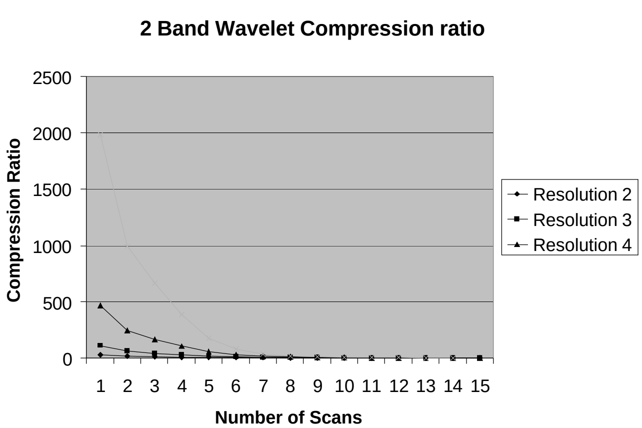


Fig 8. 2-Band EZW Compression ratio across scans

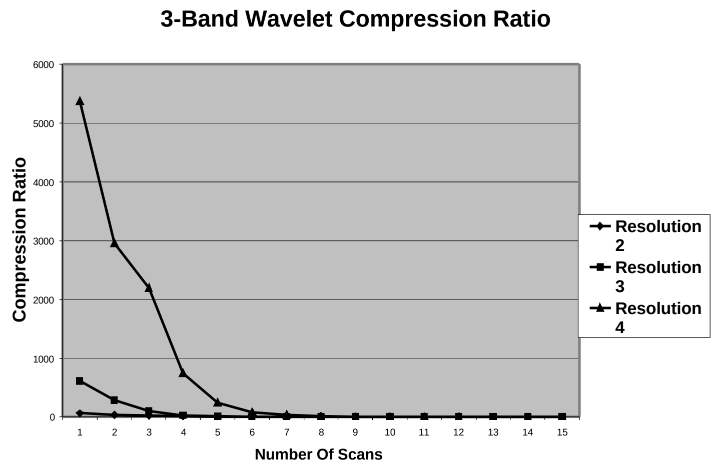


Fig 9. 3-Band EZW Compression Ratio across scans

We see that the M-Band EZW technique yields superior PSNR and compression ratio compared to the traditional EZW scheme. This is further proved in the following comparison charts.

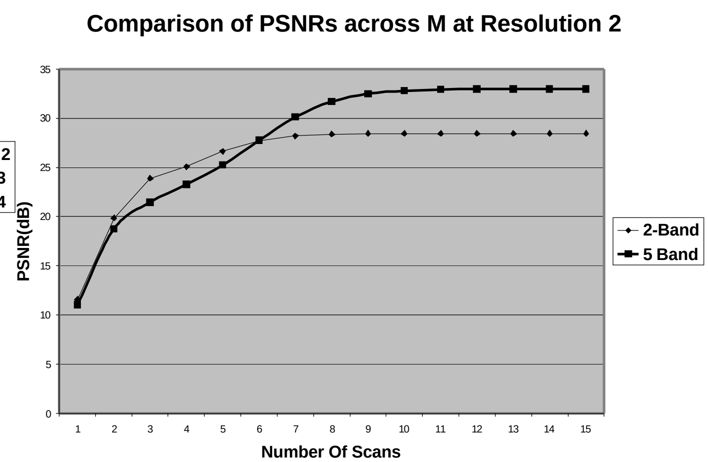


Fig 10. Comparison of 2-Band Vs 5-Band wavelet transform at resolution 2 for PSNR

While at extremely low bit-rate, the 2-Band scheme seems to be better, the 6-Band EZW overtakes the 2-Band scheme quickly and yields a much higher peak PSNR than the 2-Band scheme. Similarly the compression ratio chart (Figure 11) also affirm the better performance of the M-Band EZW compared to the 2-Band EZW scheme.

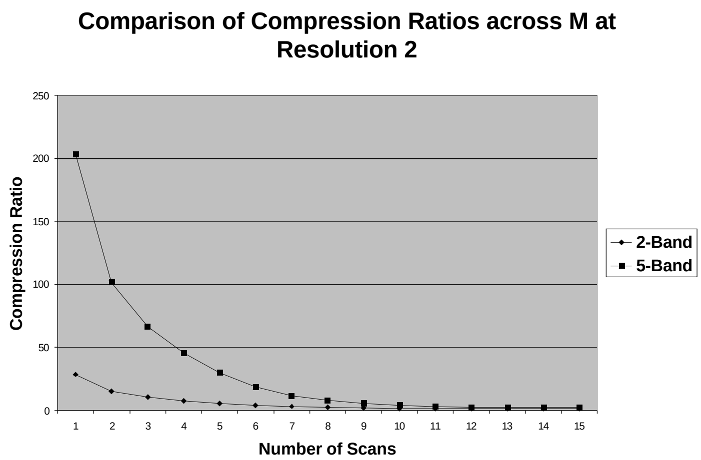


Fig .11 Comparison of 2-Band EZZW Vs 5-Band EZW for Compression ratio

5.2 M-Adaptive Quantization results

This section presents the results obtained for the M-Adaptive quantization scheme. The scheme is not found effective unless additional bits are provided to account for the increased quantization range. Without additional bits, while it provides a larger compression ration range, does not provide good PSNR. This is evident from the charts below.

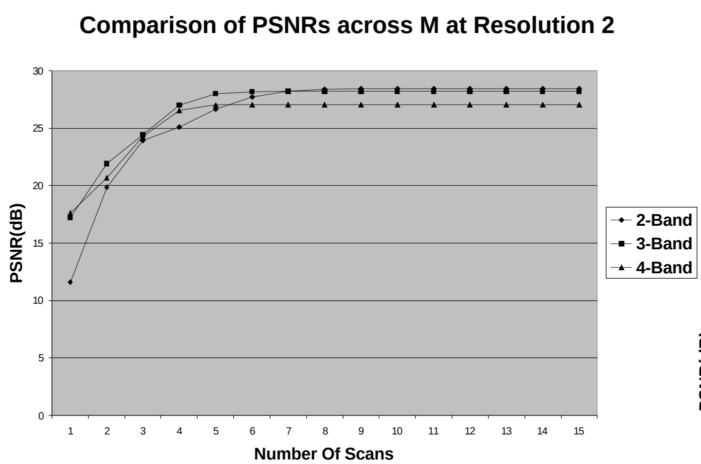


Fig.12 Comparison of PSNR for 2, 3 and 4 Band EZW

We see the PSNR in fact decreases for increasing M. The reason for this is that, while we increase the quantization range, we do not provide additional bits to accommodate more levels.

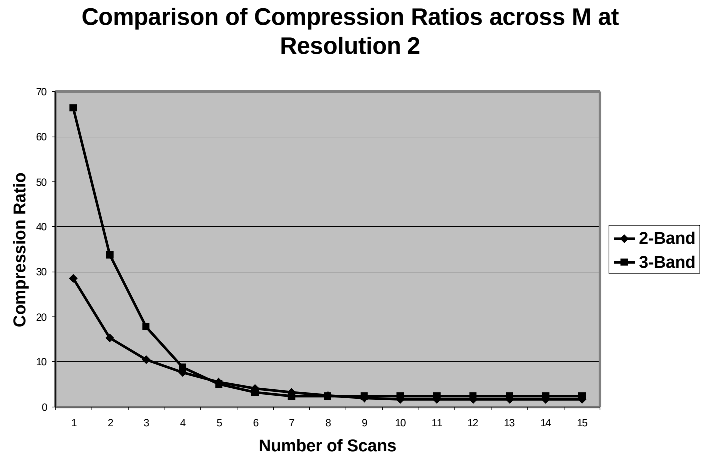


Fig.13 Comparison of compression ratio for 2,3 and 4 Band EZW

Though the PSNR has gone down, we see that the scheme does maintain a compression ratio advantage.

5.3 Special feature of M=Odd scheme

A very notable result obtained was the superior performance of M-Band schemes with M=Odd. It is observed that these schemes yield results better than M=Even. In fact, an odd numbered M-Band EZW out performs even the higher numbered Even M-Band scheme.

The following charts depict the result clearly.

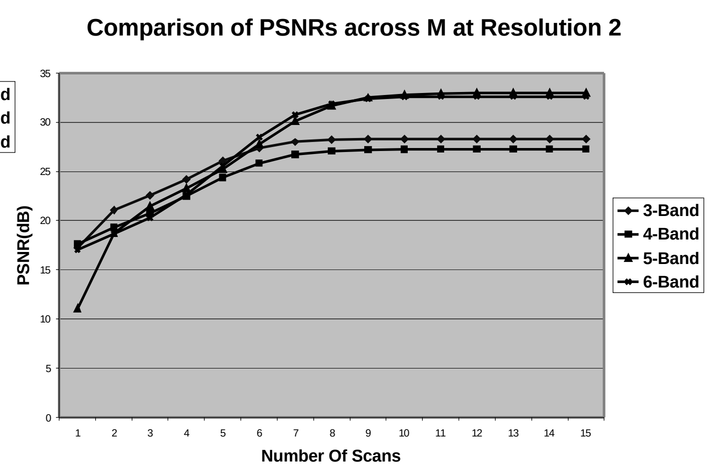


Fig. 14 Comparison of odd and even M-Band schemes – PSNR

The higher band EZW scheme maintains its compression ratio advantage though. The specialty of the odd numbered M-Band wavelet transform is still being studied.

6. COMPUTATIONAL COMPLEXITY

In this simulation, for computation of m-Band wavelet transform, type-I wavelet filters constructed using cosine modulated filter banks are used which basically forms FIR filters of length N = 2M where M = number of filter banks. So, this filter bank form stable and finite length wavelet filter banks.

Then it requires N multiplications & 2*N-1 additions per sample.

$$\therefore FLOPS / Sample = 2 * N - 1;$$

Wavelet transform for the image is computed filtering image row wise and then column wise, then, FLOPS requirement for M-band wavelet is given by

$$\therefore FLOPS = (2 * N - 1) * B^4 * M;$$

If image size is B x B, assuming it is power of M, then, each iteration of wavelet filtering will generate M bands, and size of image in each band is (B x B) / M2. Then for ith iteration, image size is (B x B) / M2i. Then total number of FLOPS for I iterations are given by

$$\therefore FLOPS = (2 * N - 1) * B^4 * M * \left(1 + \frac{1}{M^2} + ... + \frac{1}{M^{2i}}\right);$$

$$\therefore FLOPS = (2 * N - 1) * B^4 * \frac{M}{M^{2i}} * \left(\frac{M^{2i+2} - 1}{M^2 - 1}\right);$$

$$\therefore FLOPS = (2 * N - 1) * B^4 * M;$$

$$M^{2i+2} >> 1 \text{ and } M^2 >> 1$$

Thus for M band wavelet transform, computational complexity is directly proportional to M.

7. CONCLUSIONS

The simulation results are presented for 256 x 256 “Lenna” image to investigate the performance of M-band wavelet transform for M=3 and M=4 in comparison with conventional 2-band case. The M-band Wavelet transform is implemented with appropriate zero pixel padding before computation of wavelet transform at encoder side and are removed at decoder side for the perfect reconstruction. This is due to the fact that if number of pixels in the row and columns are not equal to integer multiples of M, which results in the loss of samples. Also, Shapiro EZW coding [2] is extended for M-band case.

- It has been investigated that Shapiro EZW coding [2] can be extended to M-band case for M>2, however, in order to get proper zero wavelet tree the size of transform image virtually extended for power of M.
- As the number of resolution in the computation of the images increases EZW coding, both PSNR and compression gain increases. However, in M-band case improvement in PSNR and compression gain is higher than conventional 2-band wavelet transform.
- Thus performance of the M-band wavelet transform for M=3 and M=4 EZW coding is better, both objectively and subjectively, in comparison with the 2-band wavelet transform.
- The performance gain, in both PSNR and compression, in M-band wavelet transform over the conventional 2-band wavelet transform is mainly due to the flexibility of coding of higher bands. It is possible to improve performance of M-band wavelet transform by using non-linear adaptive quantization which is a further topic of investigation.
- The statistical reasons as to why the EZW performs differently across M-Band wavelets needs to be analyzed.

The main advantage of M-band (M > 2) wavelets over 2-band wavelets is frequency tiling which gives zoom in onto narrow band high frequency components of a signal, while simultaneously having a logarithmic decomposition of frequency channels which closely approximates HVS model & hence gives better compression than 2-band counterpart. However, in M-band wavelet system odd number of filter banks gives better compression than even number of bands which is further topic of research.

8. SAMPLE OUTPUTS

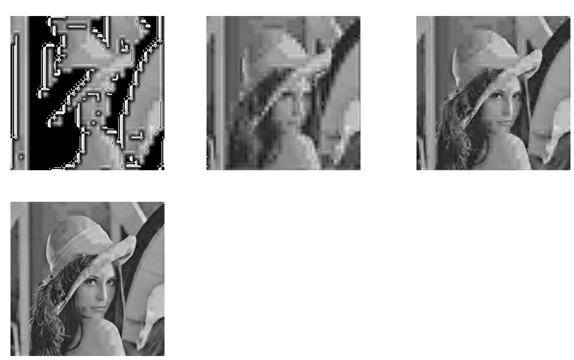


Fig. 15 Reconstructed images for 1, 3, 5 and 9 scans for 2-Band wavelet transform and Modified EZW at Resolution 3.

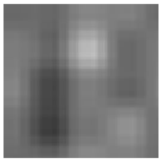



Fig. 16 Reconstructed images for 1, 3, 5 and 9 scans for the 4 Band wavelet transform and Modified EZW at Resolution 3.

9. REFERENCES

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