LOW COMPLEXITY SYNTHESIS FILTER BANK FOR SUBBAND CODING OF IMAGES

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ABSTRACT

Optimizations are performed to obtain a filter bank for subband coding of images espescially suited for VLSI implementation. Based on a filter bank consisting of two FIR filters combined with an 8 point DCT, we investigate how the quantization of filter coefficients and twiddle factors in different algorithms affects the quality of the filter bank. It is found that a DCT based on the Stasinksi algorithm with twiddle factors of only 5 bits together with FIR filter coefficients of 10 bits, gives a filter bank with high coding gain, no blocking artifacts and limited ringing. The VLSI complexity is comparable to that of DCT transforms.

1 INTRODUCTION

The discrete cosine transform (DCT) represents the prevailing decomposition method in image coding. This is partly due to the misconception that the alternative, subband filter banks, although giving better performance, require much higher computational load. Today many researchers have concluded that filters with short kernels represent a viable alternative to the DCT.

We have earlier developed a uniform filter bank structure [1] which retains the high coding gain of subband coders while having a decoder complexity close to that of the cosine transform. Also, the ringing artifacts are limited and blocking effects are eliminated. In this paper we describe the optimizations performed to find the optimal coefficient wordlengths in the synthesis filters. A nonresiprocal application is assumed where the decoder complexity is the most important. Rounding of coefficients affects the frequency responses of the filter bank and careful simulations are needed to obtain satisfying quality.

The obtained system is well suited for VLSI implementation. With short coefficient wordlengths the chip area is reduced. Depending on the chosen VLSI architecture the number of coefficient bits might also influence the clock frequency and thereby the power consumption.

2 SYNTHESIS FILTER BANK STRUCTURE

In a previous work [2] an optimization method was developed to obtain high quality filter banks. In an experiment a parallel, uniform and separable filter bank with 8 channels in each dimension was considered. When varying the synthesis filter lengths, it was found that a good compromise between ringing and blocking effects was obtained by using longer filters in the lower bands and short filters in the upper bands. Further experiments showed that good performance was reached with filters of length 24 and 16 in band 1 and 2, respectively, and filters of length 8 in the 6 upper bands. It was discovered that the unit sample responses of the filters in band 3 to 8 were quite close to the corresponding filters of an 8 point discrete cosine transform. Optimizations were then performed forcing the coefficients of the 6 upper channels to DCT-coefficients while at same time trying to satisfy the following criteria:

- Close to perfect reconstruction.
- Reduction of blocking effects.
- Maximum coding gain over PCM.

The only length constraint put on the analysis filters was a maximal length of 32.

Fig. 1 shows the synthesis filter bank. The 6 upper channels are substituted by an 8 point DCT. Included in the blocks is the upsampling from the low sampling frequency f_S to the frequency $8f_S$.

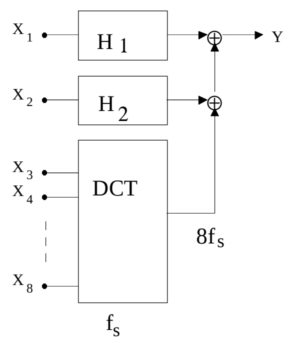

Figure 1. Subband coder synthesis filter bank with two FIR-filters and a discrete cosine transform.

3 DCT AND FILTER STRUCTURES

When no quantization is performed, the resulting filter responses are, of course, independent of the chosen architecture. However, the different approaches have different sensitivities to rounding of twiddle factors and filter coefficients. Among the fast DCT-algorithms we have selected the Stasinski [3] and the Vetterli algorithms [4] in the simulations. We have also considered one of the scalar product based architectures, distributed arithmetic (DA) [5]. DA is a more direct implementation of the DCT matrix and the quantization is a direct rounding of the DCT-coefficients. The Vetterli and Stasinski algorithms with the two lower channel inputs removed are shown in Fig.2 and Fig.3.

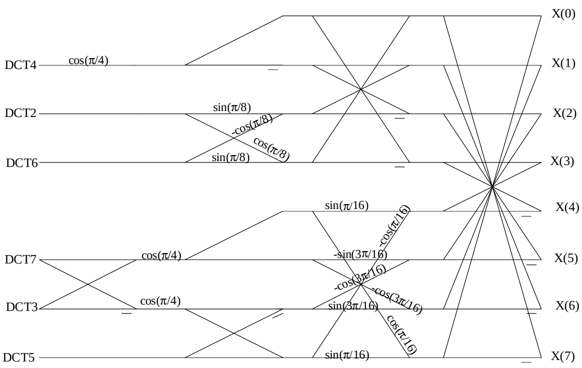

Figure 2. The Stasinski algorithm.

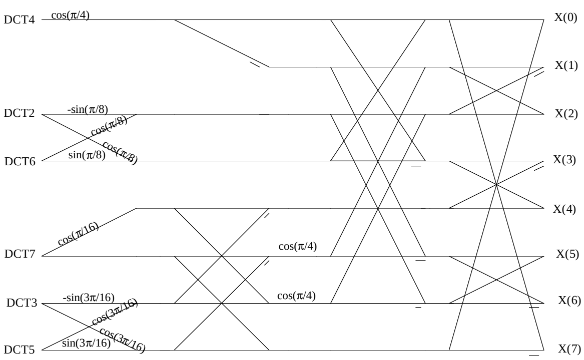

Figure 3. The Vetterli algorithm

Among the different structures for the FIR-filters in band 1 and 2, a simple polyphase solution [6] turns out to be the best alternative. This means that the filter coefficients are quantized directly.

4 OPTIMIZATION PROCEDURE

The following procedure was used to find the optimal filter banks starting with an initial filter bank optimized for the critera in section 2:

1. The synthesis filters in band 3 to 8 were set equal to the resulting DCT coefficients after quantizing the given DCT-structure.
2. Optimization of the analysis filter bank and the two lower bands in the synthesis filter bank was performed with the DCT-coefficients of the filters in band 3 to 8 locked.
3. The synthesis filters in band 1 and 2 were quantized directly.
4. The optimization program was run once without iterations to find the analysis filter bank that best matches the quantized synthesis filter bank.

To assess filter bank performance, the Peak Signal to Noise Ratio (PSNR) of the reconstructed image was calculated for all sets of coefficients, at a given bit rate in a model employing adaptive bit allocation. The PSNR is a quality measure that contains the points listed in section 2 except for blocking effects. The unit sample and frequency responses of the filters are also used to gain information. Finally, the reconstructed image is used as a subjective quality criterion to check for possible visual degradations.

5 FILTER QUANTIZATION

In the following discussion we use the notation *algo_nm* where *algo* denotes the DCT-algorithm, *n* is the number of bits in the twiddle factors and *m* is the number of bits in the FIR-filter coefficients.

5.1 Stasiski based filter banks

The filter banks based on the Stasinski algorithm were simulated with the twiddle factors rounded to 4, 5 and 7 bits. For each DCT-quantization the FIR filters in band 1 and 2 were quantized with from 2 to 12 bits. As input stimulus the images *'Lenna'* and *'Kiel Harbour'* were used. The resulting PSNRs with *'Lenna'* as input is shown in Fig.4. Included as a performance limit is DCT-quantization without quantization of the FIR-filters. Surprisingly, *stas5* performs better than *stas7*. This is probably due to a closer match to the optimal coefficients for the tested image. Remember, the ideal DCT is not necessarily optimal for the coding gain. 10 bits coefficients in the FIR-filters seem to be sufficient. Using only 6 bits shows a clearly decrease in the PSNR.

Results with the image *'Kiel Harbour'* as stimulus are shown in Fig.5. Due to the larger complexity of this image, the coding bit rate is increased from 1.0 bit/pel to 2.0 bits/pel. Based on the results from *'Lenna''* we decided to simulate only with FIR-filters quantized with a minimum of 6 bits. A strange effect occures for the curves *stas5* and *stas7*. They show a peak in the performance for FIR-filters with 7 bits. *Stas5* has an even higher PSNR for unquantized than for quantized FIR-filters. The difference is, however, quite small and indicates that the wordlengths should be determined based on simulations with more than one image. The interesting candidates are obviously *stas5* with 7, 8 and 10 bits filter coefficients.

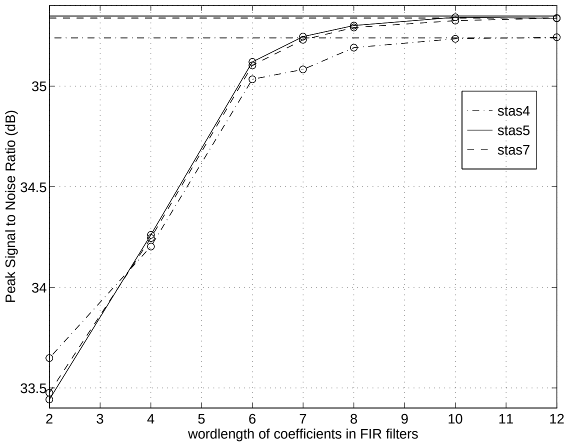

Figure 4. PSNR for Stasinski based filters using the image 'Lenna' coded at 1.0 bit/pel. *The horisontal lines indicate the PSNR if the filters in band 1 and 2 are not quantized.*

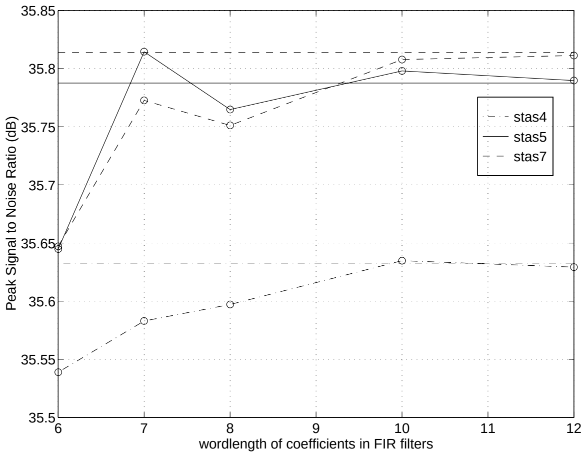

Figure 5. PSNR for Stasinski based filters using the image 'Kiel Harbour' *coded at 2 bit/pel. The horisontal lines indicate the PSNR if the filters in band 1 and 2 are not quantized.*

When looking at the shapes of the unit sample responses of the low pass synthesis filters of these three filter banks (Fig.6), it is clearly observed that *stas510* has a smoother shape than the other two. Smoothness is important to avoid blocking effects and obtain good interpolation.

The frequency responses of the low pass filters of the three filter banks are shown in Fig.7. To avoid blocking effects the attenuation should be large at the relative frequencies 0.125, 0.25, 0.375 and 0.5. This is better satisfied by *stas510* than by *stas58*.

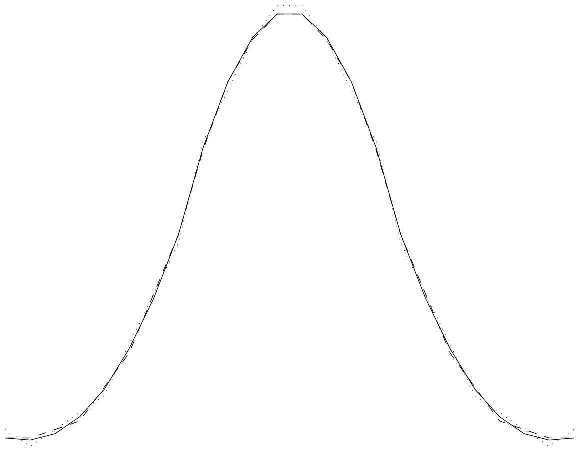

Figure 6. Shapes of the synthesis impulse responses of the LP filters of stas57 *(dotted),* stas58 *(dashed) and* stas510 *(solid).*

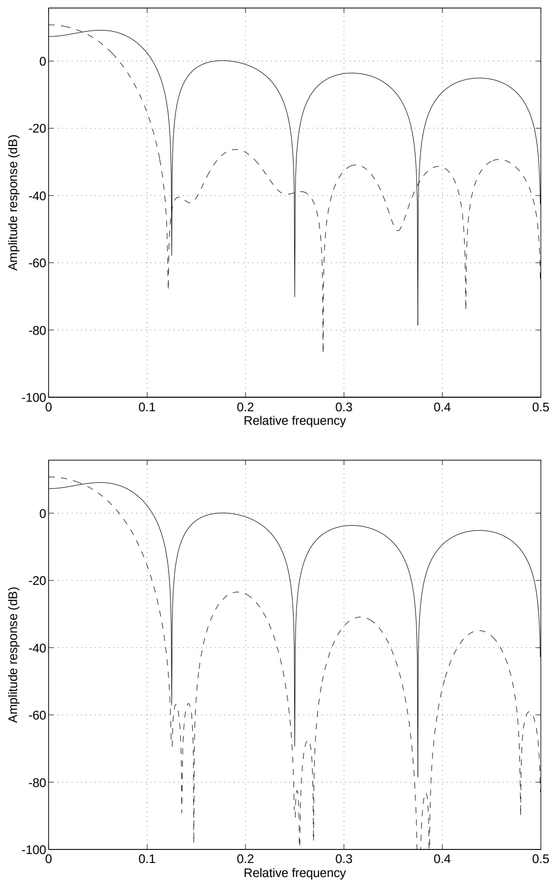

Figure 7. Frequency responses of the LP filters of stas58 *(top) and* stas510 *(bottom). Solid: analysis, dashed: synthesis.*

Visual degradations for the filter banks *stas57* and *stas58* could not be observed except by performing an operation called *pixel windowing* that only shows pixel values between certain limits. A regular pattern then appeared in an area that is smooth in the original image. This indicates that artifacts might occure in other images.

5.2. Vetterli based filter banks

Filters based on the Vetterli DCT were simulated with twiddle factors quantized with 5 bits and FIR-filters quantized with from 6 to 10 bits. Fig. 8 shows PSNR values when the image '*Kiel Harbour*' is used as input. *Stas5* is included for the sake of comparison.

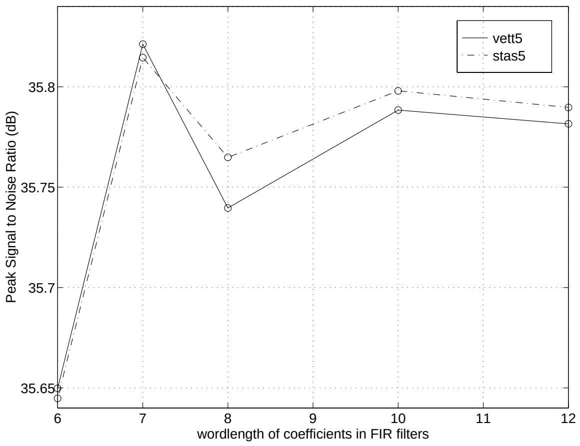

Figure 8. PSNR for Vetterli based filters using the image 'Kiel Harbour' *coded at 2 bit/pel. The results for* stas5 *are included as a reference.*

The peak at 7 bits FIR-filter coefficients is still present. The performance of *vett5* is sligthly worse than for *stas5*. 10 bits FIR filter coefficients should be sufficient also for *vett5*. Only 6 bits gives a significant decrease in the PSNR.

The shape of the LP synthesis unit sample responses and the frequency responses for the LP analysis and synthesis filters were also studied. The unit sample response of *vett510* can hardly be distinguished from that of *stas510*. A comparison of the frequency responses of *vett510* and *stas510* shows a somewhat better attenuation at the critical frequency points for *stas510*. There is no visual differences between *vett510* and *stas510* in the reconstructed image and *pixel windowing* on *vett10* does not reveal any artifacts.

5.3. DA based filter banks.

Filters based on a DA realization of the DCT were simulated with DCT coefficients of 5, 6 and 7 bits. The FIR-filter coefficients were rounded to 8 and 10 bits. The PSNR values for *da6* are higher than for *da5*, but lower than for *vett5* and *stas5*. The difference between FIR-filters quantized with 8 and 10 bits are smaller than for the Stasinski and Vetterli filter banks.

The shapes of the LP unit sample responses are quite similar to the corresponding responses based on Stasinski and Vetterli DCTs. The LP frequency responses have about the same attenuation as the Vetterli filters, that is sligthly larger than the Stasinski filters.

6 CONCLUSION

The simulation results indicate that 5 bits twiddle factors and 10 bits FIR-filter coefficients in band 1 and 2 are sufficient to obtain the same coding quality as with unquantized filter banks. No visual artifacts due to coefficient quantization can be detected in the reconstructed image. The hardware costs of using more bits will not justify a marginally increased gain. When considering only the rounding effects, the Stasinski DCT is to be preferred, giving slightly better results than Vetterli and DA DCTs.

Standard DCT coders normally use 12 bits DCT-coefficients. This means that the complexity is more than doubled compared to our DCT. The complexity of the entire subband coder with FIR-filters included is thus not significantly larger than for transform coders.

Acknowledgement

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