DESIGN OF LINEAR PHASE COSINE MODULATED FILTER BANKS FOR SUBBAND IMAGE COMPRESSION

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ABSTRACT

This paper proposes to investigate a new class of M-band linear phase modulated filter banks. In particular we propose to investigate different methods for designing the prototype filter based on perceptual measures such as reduced image artifacts as well as more traditional measures such as coding gain and mean square difference. Image compression at low bit rates typically introduces image artifacts annoying to the human observer. One can classify the various types of compression artifacts in to three categories: *blurring*, *blocking* and *ringing*. Each of these artifacts will have a different visual impression on the observer and typically blurring will be the most acceptable distortion; blocking and ringing artifacts tends to cause more visual interference to the observer. Blocking is typically found in transform coding based algorithms (e.g., the JPEG standard which is based on the DCT) while ringing is typically found in subband image coders and is due to the coarse quantization of the high frequency bins.

1. M-BAND AND 2M-BAND DCT/DST MODULATED FILTER BANKS

The M channel maximally decimated modulated filter bank (MFB) has undergone an extensive study over the last few years [4]. Until recently only a class of MFBs referred to as a Class B MFBs [4, 2] were known. In these MFBs it can be shown that linear phase is impossible to achieve. Notice however that linear phase paraunitary filter banks have been designed [6]. This paper proposes to use the new Class A MFBs for even M first constructed in [1].

The design of a MFB typically requires the design of one or two prototype filters which result in a filter bank where each filter does not have linear phase. The recent discovery of this new class (Class A) modulated filter banks was first proposed by Lin and Vaidyanathan [5]. These results were further extended to cover a broader class of MFB's [1]. The novelty of this new class of MFB's was that both analysis and synthesis filters would have linear phase.

Since linear phase is well know to be a desirable property for image coding applications with coarsely quantized subbands it is expected that this new class of filter banks will have good subband coding properties.

1.1. Modulated Filter Banks

Define

$$k_i = \begin{cases} \frac{1}{\sqrt{2}} & i \in \{0, M\} \\ 1 & \text{otherwise,} \end{cases} \tag{1}$$

$$\alpha = \begin{cases} M-1 & \text{Type 1 FB} \\ M-2 & \text{Type 2 FB} \end{cases} \tag{2}$$

and

$$J = \begin{cases} \frac{M}{2} & \text{Type 1 FB, } M \text{ even} \\ \frac{M-1}{2} & \text{Type 1 FB, } M \text{ odd} \\ \frac{M-2}{2} & \text{Type 1 FB, } M \text{ even} \\ \frac{M}{2} & \text{Type 1 FB, } M \text{ odd} \end{cases} \tag{3}$$

Given the above definitions we can now define the new MFBs. For α even (i.e., Type 2 and M is even or Type 1 M is odd) a DCT/DST I, $2M$ channel FB is obtained from the prototype filters $h(n)$, and $g(n)$ as [5]:

$$h_i(n) = k_i h(n) \cos\left(\frac{\pi}{M} i (n - \frac{\alpha}{2})\right), i = 0, \ldots, M \tag{4a}$$

$$h_{M+i}(n) = h(n-M) \sin\left(\frac{\pi}{M} i (n - \frac{\alpha}{2})\right), i = 1, \ldots, M-1 \tag{4b}$$

$$g_i(n) = k_i g(n) \cos\left(\frac{\pi}{M} i (n + \frac{\alpha}{2})\right), i = 0, \ldots, M \tag{4c}$$

$$g_{M+i}(n) = -g(n+M) \sin\left(\frac{\pi}{M} i (n + \frac{\alpha}{2})\right), i = 1, \ldots, M-1 \tag{4d}$$

For α odd (i.e., Type 1 and M is even or Type 2 M odd) a DCT/DST II, $2M$ channel FB is obtained from the prototype filter $h(n)$ as [1]

$$h_i(n) = k_i h(n) \cos\left(\frac{\pi}{M} i (n - \frac{\alpha}{2})\right), i = 0, \ldots, M-1 \tag{5a}$$

$$h_{M+i}(n) = k_i h(n-M) \sin\left(\frac{\pi}{M} i (n - \frac{\alpha}{2})\right), i = 1, \ldots, M \tag{5b}$$

$$g_i(n) = k_i g(n) \cos\left(\frac{\pi}{M} i (n + \frac{\alpha}{2})\right), i = 0, \ldots, M-1 \tag{5c}$$

$$g_{M+i}(n) = -k_i g(n+M) \sin\left(\frac{\pi}{M} i (n + \frac{\alpha}{2})\right), i = 1, \ldots, M \tag{5d}$$

Finally we also have the DCT/DST III/IV based M channel FBs [2, 4]

$$h_i(n) = h(n) \cos\left(\frac{\pi}{M} (i + \frac{1}{2})(n - \frac{\alpha}{2})\right), i = 0, \ldots, M-1. \tag{6a}$$

$$g_i(n) = g(n)\cos\left(\frac{\pi}{M}(i+\frac{1}{2})(n+\frac{\alpha}{2})\right), i = 0,\ldots,M-1. \quad (6b)$$

A DCT/DST I/II $2M$ filter banks will be referred to as a class 'A' modulated filter and a DCT/DST III/IV M as a class 'B' modulated filter bank. Most results in the literature pertains to Type 1, Class B modulated FB's. Notice furthermore that as with the Class B MFBs, $g(n)$ can be obtained form $h(n)$ by a shift or designed individually.

It can be shown that if the prototype filter $h(n)$ has linear phase then for a class A modulated filter bank it follows that the filters are linear phase. This is not true for the class B modulated filter banks and in fact it has been proved that class B modulated filter banks can not have linear phase [1].

2. DESIGN OF OPTIMAL PROTOTYPE FILTERS FOR IMAGE COMPRESSION

Over last few years there has been a considerable effort in improving the image quality for low bit rate (less that 0.25 bpp) still image compression. One of the areas of interest is to design subband coders which are optimal with respect to minimizing visual distortion. Low bit rate image coders tends to exhibit considerable visual distortion. It is believed that to obtain high quality image coders at low bit rates the coders needs to incorporate perceptual coding criteria. For an excellent review of signal compression based on models of human perception see [3].

To achieve low bit rates with a subband coder one traditionally has to use long filters. The down side to this is that long filter results in a considerable ringing artifact around image discontinuities. To compensate for this there are currently two direct approaches: (i) use shorter filter lengths which results in less ringing but introduces more blurring, (ii) use a space varying filter bank which use long filters for smooth image regions and short filter for image discontinuities. In this investigation we will be exploring both these methods in parallel.

In Fig. 1 we show a region of the Lenna image which has been subband filtered with a Type 1, Class B MFB, quantized (coarsely) with a uniform quantizer and reconstructed. Notice the non-desirable texture like noise that has been introduced. In Fig. 2 we show the same region of the Lenna but now with the new Type 1, Class A MFB, quantized with the same uniform quantizer and reconstructed. Notice the smoothness in this image compared to the previous image.

3. ONGOING AND FUTURE RESEARCH

In this research we will investigate the advantages of using this new class of M-band linear phase DCT/DST Type I-IV modulated filter banks. Our research will in particular consider the the effect of varying M, investigate different methods for designing "optimal" (in terms of coding gain, reduced subband coding artifacts, perceptual measures etc.) prototype filters. We will also investigate the trade off involved in choosing filter lengths. In particular we will investigate the possible advantages or disadvantages of using space varying filter banks as opposed to a fixed filter bank with short filter lengths to deal with image discontinuities.

Acknowledgments

The authors wishe to thank Prof. Vaidyanathan for discussions regarding this new class of linear phase modulated filter banks. Supported for this research is provided by ARPA, BNR and TI

REFERENCES

[1] R. A. Gopinath. Modulated filter banks - a general theory. Technical Report CML TR94-01, Computational Mathematics Laboratory, Rice University, 1994.

[2] R. A. Gopinath and C. S. Burrus. Theory of modulated filter banks and modulated wavelet tight frames. In *Proc. Int. Conf. Acoust., Speech, Signal Processing*, Minneapolis, MN, 1993. IEEE.

[3] N. Jayant, J. Johnston, and R. Safranek. Signal compression based on models of human perception. *Proc. IEEE*, 81(10):1385–1422, October 1993.

[4] R. D. Koilpillai and P. P. Vaidyanathan. Cosine-modulated FIR filter banks satisfying perfect reconstruction. *IEEE Trans. SP*, 40(4):770–783, April 1992.

[5] Y-P. Lin and P. P. Vaidyanathan. Linear phase cosine modulated maximally decimated filter banks with perfect reconstruction. Technical report, California Institute of Technology, 1993.

[6] A. K. Soman, P. P. Vaidyanathan, and T. Q. Nguyen. Linear phase paraunitary filter banks: Theory, factorizations and designs. *IEEE Trans. SP*, 41(12):3480–3496, December 1993.

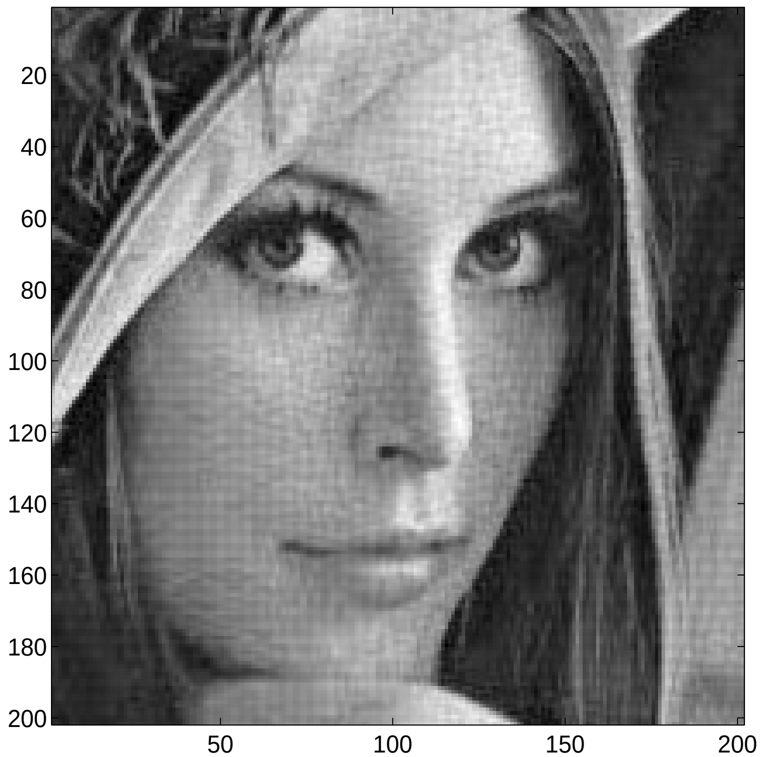

Figure 1. Subband filtered, quantized and reconstructed Lenna image using a Type 1 Class B MFB (M=4, filter length N=2Mk=16)

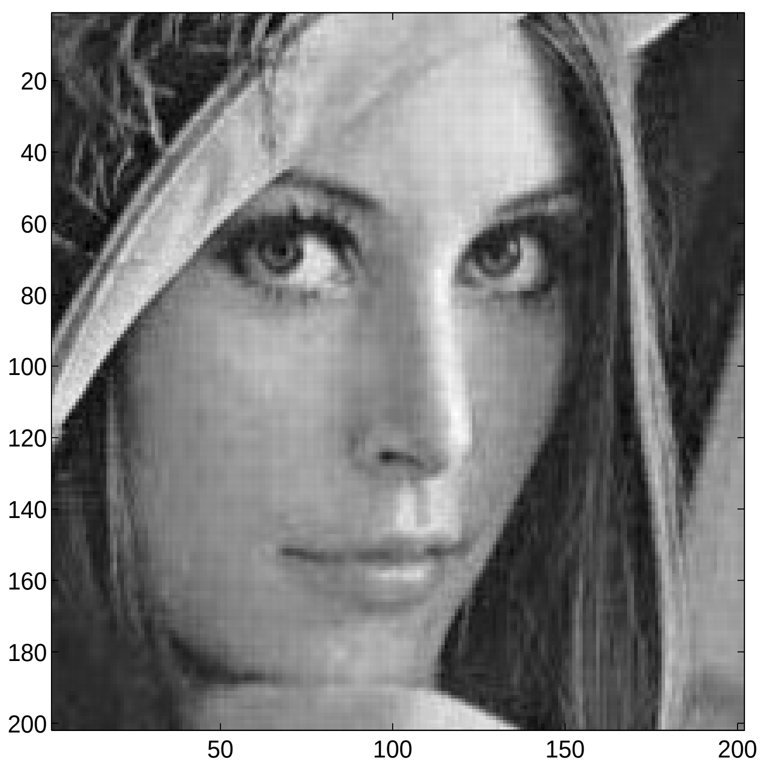

Figure 2. Subband filtered, quantized and reconstructed Lenna image using a Type 1, Class A MFB (M=8, filter length N=2Mk=16)