Image Compression Using NPR Filter Banks

Dimitar Taskovski, Momcilo Bogdanov, and Sofija Bogdanova

University Ss. Cyril and Methodius, Faculty of Electrical Engineering

Skopje-Macedonia

Abstract: *In this paper we investigate the use of linear phase near perfect reconstruction filter banks for subband image coding. The influence of the filter bank parameters such as filter length, stopband attenuation, reconstruction error, flatness and frequency selectivity to the quality of the reconstructed image is also investigated. For this purpose a large number of filter banks was designed in an optimization procedure that approximates the perfect reconstruction condition while minimizing the stopband energy of the low-pass prototype filter. From all parameters, according to experimental results, stopband attenuation and flatness of the low-pass prototype filter around half sampling frequency seem to be most important for good image quality. For a given length of the prototype filter, filter banks that perform the best results in the sense of rate-distortion performances and visual quality were selected and compared with the best biorthogonal filters for subband image coding. Coding experiments indicate that selected filter banks are competitive with the best biorthogonal filters in the sense of objective and subjective performances of Lena and Barbara images coded at rate above 0.5 b/p.*

I. INTRODUCTION

Subband image coding has been shown to be an effective technique for high quality coding at low bit rates [1]. The basic idea of subband coding is to split up the frequency band of the signal and to code each subband separately using a coder and a bit rate closely matched to the statistics of that particular band. The technique of subband coding for a two band system is explained in Fig.1. A signal is passed through the analysis filters. Due to the reduced bandwith of the resulting components they may be subsampled to yield the subbands. Following this each subband is encoded, transmitted and, at destination, decoded. To reconstruct the signal, the subbands are upsampled to the sampling rate of the input and passed through the synthesis filter bank. The filtered components are then added to form the reconstructed signal. In the case of images, the band-splitting is done in each direction (horizontal and vertical). Further the scheme can be iterated on the LL band to yield multiple levels of a pyramid.

It follows that the main building block of subband coding system is the classical two-band filter bank shown in Fig. 1. The choice of filter bank is a critical issue that affects image quality as well as system design. It is well known that improperly designed filter banks can cause aliasing, amplitude distortion, and phase distortion. This means that the filters in the bank must be designed in order to achieve exact reconstruction in absence of coding errors. Generally, the design of a two-band filter bank with perfect reconstruction (PR) property is not such a big problem [2]. However, in order to exploit the advantages of subband coding, filters in the bank should satisfy additional constraints. Hence the overall performance of subband coding systems depends of the combination of many different factors associated with the individual filters in the filter banks and the properties of the overall filter bank.

The perfect reconstruction condition is required for lossless compression as in medical imaging. However, in low bit rate compression, the reconstruction error is dominated by the quantization noise. Any aliasing distortion of a near perfect reconstruction (NPR) filter bank would be masked by the quantization noise. It is doubtful whether keeping the PR property still makes sense in that case. Relaxing this condition allows more freedom for the optimization, and a well-designed NPR filter bank could even outperform a PR filter bank [3].

In this paper we investigate the use of linear phase near perfect reconstruction banks for subband image coding. Namely, we investigate the influence of certain filter characteristics such as filter length, stopband attenuation, reconstruction error, flatness and frequency selectivity on the objective and subjective performance of encoded images. For this purpose more than 150 banks have been designed using different design parameters in the optimization procedure that minimizes a single objective function consisting of energy of overall reconstruction error and stopband energy of the low-pass prototype filter. From all designed banks for a given length of the prototype filter we have selected the best banks for subband image coding. Then these banks have been compared with the best biorthogonal filters for subband image coding in the sense of rate-distortion performance and visual quality of reconstructed images.

II. Design of Two–Band Filter Bank

The basic structure of a two-band filter bank is shown in Fig. 1. The transfer function of a two-band filter bank is given by [2]:

$$\begin{aligned}\hat{X}(z) &= \frac{1}{2}\left[H_0(z)F_0(z) + H_1(z)F_1(z)\right] X(z) \\ &+ \frac{1}{2}\left[H_0(-z)F_0(z) + H_1(-z)F_1(z)\right] X(-z)\end{aligned} \tag{1}$$

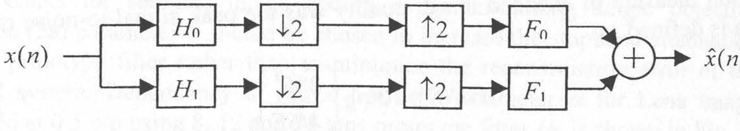

Fig. 1. Two-band filter bank.

The first term is the desired term, while the second term represents aliasing error due to the change of sampling rate in the bank. By assuming that $H_1(z) = H_0(-z)$, $F_0(z) = H_0(z)$, $F_1(z) = -H_0(-z)$, in order to cancel the aliasing and that low-pass prototype filter $H_0(z)$ is a linear-phase FIR filter with even number of taps, a general objective function for the design of quadrature mirror filter (QMF) banks is formulated as

$$E = E_r + \alpha E_s \tag{2a}$$

where E_r denotes the energy of reconstruction error and is given by

$$E_r = \int_0^{\pi} \left[\left| H_0(e^{j\omega}) \right|^2 + \left| H_0(e^{j(\omega+\pi)}) \right|^2 - 1 \right]^2 d\omega \,. \tag{2b}$$

E_s denotes the stopband energy related to the low-pass prototype filterH_0 and is given by

$$E_s = \int_{\omega_s}^{\pi} \left| H_0(e^{j\omega}) \right|^2 d\omega \,. \tag{2c}$$

The parameter α in (2a) is a positive weight that can be used to control stopband attenuation for filter H_0, and ω_s is the frequency of the stopband edge.

From the above, it is clear that the design of a quadrature mirror filter is essentially a problem of finding a low-pass filter H_0 with good stopband attenuation maintaining at the same time $|H(e^{j\omega})| \approx 1$ for all ω, where $H(e^{j\omega})$ is the frequency response of overall system. There are several proposed techniques for minimizing a single objective function of several variables (2a). In this paper we use linear-phase QMF banks by the design methoddescribed in [4]. For some conclusions we also use the QMF banks by the algorithm proposed in [5].

III. Experimental Results and Discussion

Specifying the stopband frequency ω_s, the weight factor α and number of taps N, large number of QMF banks was designed using optimization procedures proposed in [4] and [5]. In order to investigate influence of certain filter characteristics such as filter length, stopband attenuation, reconstruction error, flatness, and frequency selectivity to the quality of the image, coding simulations were performed for the luminance components of the 512x512 Lena and Barbara images. Lena and Barbara images were coded at wide range of bit rates using efficient wavelet-transform-based image coding scheme [3]. A common measure of encoded image quality was the peak signal-to-noise ratio, which is defined as

$$PSNR = 10\log\left(\frac{255^2}{MSE}\right) \tag{3}$$

where MSE denotes the mean-squared-error.

According to the results obtained, some observations about filter characteristics can be made. For QMF banks the rate-distortion performance improves with the increasing length of the prototype filterH_0. This is especially obvious for the filter length below 12. However, for filter length greater than 12, changes in *PSNR* become insignificant. Using longer filters in subband image coding ringing noise is produced around edges. On the other side, short filter lengths involve blocking effects. This means that the filter length is fundamental parameter in design process. In our further investigations we mainly use 8, 12 and 16 taps filters.

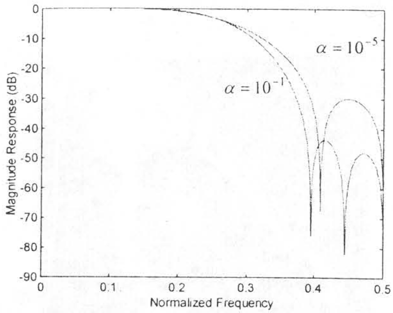

Fig. 2 Frequency response of 16 taps prototype filter H_0 for two different values of the parameter α.

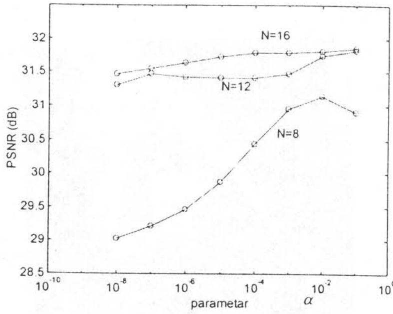

Fig 3. Dependency of *PSNR* from parameter α for 256x256 Lena image encoded at 0.5 b/p using 8, 12 and 16 taps prototype filter.

The frequency response of 16 taps prototype filter H_0 for two different values of α is shown in Fig. 2. The effect of the parameter α is clearly seen from the figure. Namely, larger value of α leads to better stopband attenuation. On the other side using larger α during the design process results in larger reconstruction error of the overall system. Thus, the choice of α is trade-off between stopband attenuation of the low-pass prototype filter and overall reconstruction error. To investigate the influence of the parameter α on the quality of the encoded image we have designed QMF banks with same length prototype filter, same stopband frequency ω_s and different values of parameter α. Experimental results show that QMF banks with better stopband attenuation of the prototype filter have better *PSNR* performance. This means that in the design process of QMF banks for subband image coding, with minimizing single objective function (2a) parameter α should be chosen to increase the stopband attenuation of the prototype filter rather than to minimize the reconstruction error of the overall system. Dependency of *PSNR* from the parameter α for Lena image encoded at 0.5 b/p using 8, 12 and 16 taps prototype filter H_0 is shown in Fig. 3. It can be seen from the figure that impact of the stopband attenuation on rate-distortion performance is more expressed for short filter lengths.

We also investigate the influence of frequency selectivity of the prototype filter on rate-distortion performances and visual quality of the encoded images. Filters with different frequency selectivity have been designed mainly using different values of ω_s for given values of α and N in the design process. Experimental results show that flatter, thus less frequency selective filters are best for given number of taps. This means that frequency selectivity of the prototype filter is not essential for subband image coding. On the contrary, flatness is more important. This is especially obvious for short filter lengths. Impact of frequency selectivity of low-pass prototype filter on visual quality of reconstructed Lena images after encoding at 0.5 b/p is given in Fig. 4. Using more flat filters, blocking effects are reduced.

Fig. 4. Flatness versus frequency selectivity. Using more flat filter for given length of the low-pass prototype filter, blocking effects are eliminated.

From all designed QMF banks for given number of taps we have selected the best in sense of rate-distortion performance and visual quality of reconstructed images. The coefficients of the low-pass prototype filter of the QMF banks that have performed the best results are given in Table I.

TABLE I

COEFFICIENTS OF THE LOW-PASS PROTOTYPE FILTER OF THE QMF BANKS THAT PERFORM THE BEST RESULTS FOR GIVEN FILTER LENGTH N. THE COEFFICIENTS ARE LISTED FROM CENTER TO END.

N	COEFFICIENTS OF THE LOW-PASS PROTOTYPE FILTER			
8	0.49374959380374	0.05920879398864	−0.06004904696292	0.00709065917054
12	0.48579119834158	0.08313373573575	−0.08061339367786	−0.00047959433364
	0.01470554764697	−0.00253749371280		
16	0.48564860670602	0.08482208241761	−0.08195896470242	−0.00106943775495
	0.01596359254100	−0.00310394229397	0.00022794975618	−0.00052988666946

In order to assess efficiency of the linear-phase NPR QMF banks for subband image coding, selected QMF banks have been compared with the best biorthogonal filters for image coding [6]. As criteria for comparison we use objective and subjective performance of the encoded images. The results obtained after encoding Lena and Barbara images at different rates show that selected linear-phase NPR QMF banks are competitive to the best known biorthogonal filters for image coding with respect to *PSNR* performance.

In addition to quantitative *PSNR* comparison, the reconstructed images have been evaluated to assess the perceptual quality. At rate above 0.5 bit/pixel there are no differences in the quality of the reconstructed images obtained with QMF banks with prototype filter length greater than 12 and biorthogonal filters. At a rate below 0.5 bit/pixel, 9/7 and 6/10 biorthogonal filters perform slightly better than QMF banks. As we have been expecting, in our experiments, the most disturbing visual artifacts have been ringing noise and blocking effects. At low bit rates, ringing noise affects the quality of reconstructed images considerably when QMF banks with longer prototype filter are employed. For short unit pulse responses blocking effects have been main distortion.

IV. Conclusions

We have investigated the influence of filter bank parameters on the quality of encoded image. NPR filter banks have been obtained in the optimization procedure that minimize single objective function consisting of energy of overall reconstruction error and stopband energy of the low-pass prototype filter. Experimental results show that weighting factor in objective function should be chosen to minimize stopband energy of the prototype filter at the expense of the overall reconstruction error. Filter length is trade-off between blocking effects and ringing noise. Ringing noise can be eliminated if short filter lengths are used. Now if frequency response is optimized to be more flat around half sampling frequency rather than to have good frequency selectivity blocking effects can be reduced. Coding experiments indicate that selected filter banks that perform the best results are competitive with the best biorthogonal filters for subband image coding in the sense of objective and subjective performances of Lena and Barbara images coded at rate above 0.5 b/p.

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