Optimal Design of Filter Banks for Texture Discrimination

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ABSTRACT

In this paper, we present an optimum design of two-band Finite Impulse Response (FIR) Quadrature Mirror Filter bank (QMF) for maximum possible discrimination between textured images. There are several applications, which may not require reconstruction of signal from its transformed coefficients e.g. texture analysis, remote sensing etc. For such applications, features are extracted at different frequency resolution scales. Hence, it is extremely important that transformed image coefficients should be distortion less, which is not possible in practice. Therefore, we present an optimal design method for maximum possible discrimination between any particular classes of textures with minimum possible coefficient error. In order to obtain the desired results, the optimization routine adjusts relative error weighting along with passband and stopband edges for the design of symmetric response FIR filter.

Keywords

Quadrature mirror filters, Texture analysis, Perfect reconstruction, Texture discrimination, Euclidean distance.

1. INTRODUCTION

The evaluation of texture features is important for several image processing applications such as biomedical imaging, industrial applications, satellite imagery etc. There is a range of feature extraction methods for texture analysis, and it has been under consideration by numerous researchers for decades. [Tuc01a]. Statistical analysis includes gray level co-occurrence, primitive length, geometrical moment analysis etc [Pra01a]. A weakness shared by all these texture analysis schemes is that the image is analyzed at one single scale. However, this limitation can be overcome by analyzing the signal at different scales with the help of filter banks. In case of filter banks, a common requirement of design objective is that the reconstructed output signal should be a delayed replica of input signal. A classical method for designing near perfect reconstruction QMF was proposed by Johnston [Joh01a]. It consists of selecting the filter coefficients such that overall transfer function becomes an all pass filter, while simultaneously minimizing the stopband energy of the transfer function.

In case of texture analysis, several features such as energy signatures, mean, variance, entropy etc are calculated on different decomposition levels. Therefore, synthesis filters can not play their part in removing distortion effect. Hence, it is extremely important that transformed coefficients should be error free [Lai01a][Wou01a].

In this paper, we propose a very simple, but effective optimization technique for maximum possible texture discrimination by keeping minimum reconstruction error. Our routine utilizes Parks McClellan algorithm for the design of symmetric FIR filter [Opp01a].

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This paper is organized as follows: In section 2, we introduce two-band filter banks and conditions for perfect reconstruction system. Optimization problem is defined in section 3. Computational results and conclusions are given in section 4 and 5 respectively.

2. TWO CHANNEL FILTER BANK ANALYSIS

This section briefly reviews the conditions for perfect reconstruction. In a two band QMF filter banks, the reconstructed signal is given as in Eq. (1):

$$X^{'}(z) = T(z)X(z) + S(z)X(-z) \quad (1)$$

Careful choice of synthesis filters based upon analysis filters $\{H_o(z)=H_1(-z)$, $F_o(z)=H_1(z)$ and $F_1(z)=-H_o(-z)\}$would set aliasing term S(z) = 0 and Eq.(1) reduces to:

$$X^{'}(z) = T(z)X(z)$$

$$T(z) = \frac{1}{2}\left(H_0(z)F_0(z) - H_1(z)F_1(z)\right)$$

$$T(z) = \frac{1}{2}\left(H_0^2(z) - H_1^2(z)\right) \quad (2)$$

$H_o(z)$ and $H_1(z)$ are the lowpass and highpass analysis filters and $T(Z)$ in Eq. (2) is called the overall transfer function of the alias free system.

3. OPTIMIZATION OF SYMMETRIC QMF FILTER-BANKS

In case of sub-band decomposition, filtering operation is followed by decimation, which is responsible for aliasing distortion. Effect of aliasing can be suppressed by attenuating stopband ripples more heavily in Parks McClellan algorithm. Choice of linear phase will reduce our search space for filter coefficients to half. Therefore, overall objective is to find N/2 filter coefficients which can minimize the expression given by Eq (3):

$$f = \int_0^p \left(\left|H_0(e^{jw})\right|^2 + \left|H_0(e^{j(p-w)})\right|^2 - 1 \right)^2 dw \quad (3)$$

Subject to maximizing the expression given in Eq. (4).

$$D(t_i, t_j) = \sum_k \left| E_k(t_i) - E_k(t_j) \right| \quad (4)$$

Where t_i represents the i_{th} texture image and E_k represents the energy associated with the filtered coefficients of an image at k_{th} decomposition level.

4. EXPERIMENTAL RESULTS

Images used in this paper were selected randomly from publicly available Meastex texture database [Mea01a]. Each texture image has dimensions of 256x256 and decomposed to three decomposition levels giving 10-dimensional energy feature vector.

Based upon the objective function defined in Eq. (3) and (4), we have developed an optimization routine which keeps the filter order fixed and adjusts the passband and stopband edges along with the relative error weighting factor. Desired objective is to search for coefficients of a FIR filter of any fixed order N, which gives concave curve for differentiability function and convex curve for energy error function. In an optimization routine, passband and stopband edges were adjusted for each incremental change in relative error weighting to obtain the desired objective function. In order to achieve the desired results, optimization routine was executed from filter order N=9 to N=20, passband error was varied from 0.5 to 6, keeping stopband error equal to unity. Finally, an optimization routine converged to the desired results for filter order N=20 as shown in Figure 1.

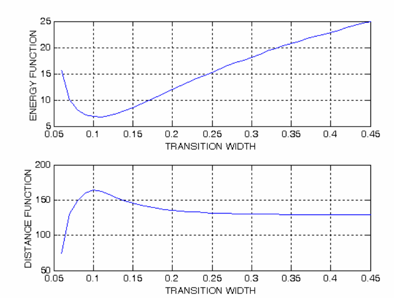

Figure 1: Energy and Differentiability Function

From Figure 1, it can be observed that the maxima and minima of the two functions coincide to a single point with respect to transition width on horizontal axis. These results are compiled in Table 1.

Filter order N	Minima of Energy Fn	Maxima of Diff. Fn	Trans. Width
20	6.79	164	$0.1p$

Table 1. Performance Comparison of Optimal Filters

Figure 2 shows the frequency response of an optimal filter (N=20

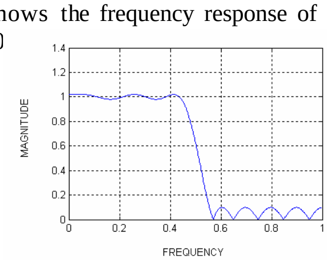

Figure 2. Frequency Response of an Optimal Filter

For performance comparison, distance between the feature vectors were calculated by using proposed optimal filter and Daubechies filter (length 20). Results are compiled in Table 2, these results show that performance of optimized filter is much better than Daubechies filter (Length 20) in terms of discriminating the texture images.

	Optimal Filter	Daubechies
Grass & Concrete	655	539
Grass & Sand	1225	951
Grass & Pebbles	636	491
Concrete & Sand	570	412
Concrete & Pebbles	21	49
Sand & Pebbles	589	460

Table 2. Comparison of Results

5. CONCLUSION AND DISCUSSION

The main concept in the analysis of signal by using filter banks is to divide the signal into its frequency contents accurately at each decomposition level. This can only be achieved with an ideal filter having a brick wall response. In practice, it is not possible to achieve such a response. Therefore, we always design a filter which performs close to an ideal case. It is observed that filter with narrow transition width performs better. Therefore, it is concluded that, symmetric impulse response filter with narrow transition width and reduced ripples in passband generally performs better as compared to orthogonal filter with greater number of vanishing moments.

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