Unconstrained Optimization Method to Design Two Channel Quadrature Mirror Filter Banks for Image Coding

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Abstract

This paper proposes an efficient method for the design of two-channel, quadrature mirror filter (QMF) bank for subband image coding. The choice of filter bank is important as it affects image quality as well as system design complexity. The design problem is formulated as weighted sum of reconstruction error in time domain and passband and stop-band energy of the low-pass analysis filter of the filter bank .The objective function is minimized directly, using nonlinear unconstrained method. Experimental results of the method on images show that the performance of the proposed method is better than that of the already existing methods. The impact of some filter characteristics, such as stopband attenuation, stopband edge, and filter length on the performance of the reconstructed images is also investigated.

Keywords: Sub-Band Coding, MSE (mean square error), Perfect Reconstruction, PSNR(Peak Signal to Noise Ratio); Quadrature Mirror filter).

1. INTRODUCTION

Quadrature mirror filter (QMF) banks have been widely used in signal processing fields, such as sub-band coding of speech and image signals [1–4], speech and image compression [5,6], transmultiplexers, equalization of wireless communication channels, source coding for audio and video signals , design of wavelet bases [7], sub-band acoustic echo cancellation , and discrete multitone modulation systems. In the design of QMF banks, it is required that the perfect, reconstruction condition be achieved and the intra-band aliasing be eliminated or minimized. Design methods [8,9] developed so far involve minimizing an error function directly in the frequency domain or time domain to achieve the design requirements. In the conventional QMF design techniques [10]-[19] to get minimum point analytically, the objective function, is evaluated by discretization, or iterative least squares methods are used which are based on the linearization of the error function to, modify the objective function. Thus, the performance of the QMF bank designed degrades as the solution obtained is the minimization of the discretized version of the objective function rather than the objective function itself, or computational complexity increased.

In this paper a nonlinear optimization method is proposed for the design of two-channel QMF bank. The perfect reconstruction condition is formulated in the time domain to reduce computation complexity and the objective function is evaluated directly [12-19].Various design techniques including optimization based [20], and non optimization based techniques have been reported in literature for the design of QMF bank. In optimization based technique, the design problem is formulated either as multi-objective or single objective nonlinear optimization problem, which is solved by various existing methods such as least square technique, weighted least square (WLS) technique [14-17] and genetic algorithm [21]. In early stage of research, the design methods developed were based on direct minimization of error function in frequency domain [8]. But due to high degree of nonlinearity and complex optimization technique, these methods were not suitable for the filter with larger taps. Therefore, Jain and Crochiere [9] have introduced the concept of iterative algorithm and formulated the design problem in quadratic form in time domain. Thereafter, several new iterative algorithms [10, 12-21] have been developed either in time domain or frequency domain. Unfortunately, these techniques are complicated, and are only applicable to the two-band QMF banks that have low orders. Xu *et al* [10,13,17] has proposed some iterative methods in which, the perfect reconstruction condition is formulated in time domain for reducing computational complexity in the design. For some application, it is required that the reconstruction error shows equiripple behaviour, and the stopband energies of filters are to be kept at minimum value. To solve these problems, a two-step approach for the design of two-channel filter banks was developed. But the approach results in nonlinear phase, and is not suitable for the wideband audio signal. Therefore, a modified method for the design of QMF banks using nonlinear optimization has developed in which prototype filter coefficients are optimized to minimize the combination of reconstruction error, passband and stopband and residual energy.

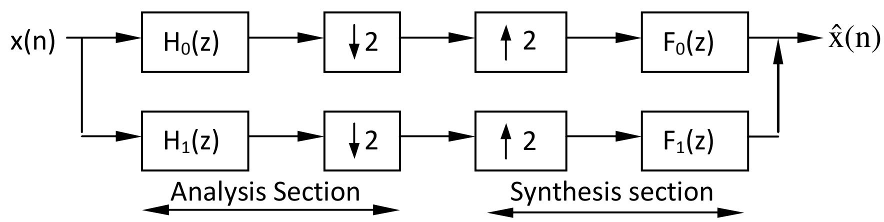

FIGURE1: Quadrature Mirror Filter Bank

A typical two-channel QMF bank shown in Figure 1, splits the input signal *x(n)* into two subband signals having equal band width, using the low-pass and high-pass analysis filters $H_0(z)$ and $H_1(z)$, respectively. These subband signals are down sampled by a factor of two to achieve signal compression or to reduce processing complexity. At the output end, the two subband signals are interpolated by a factor of two and passed through lowpass and highpass synthesis filters, $F_0(z)$ and $F_1(z)$, respectively. The outputs of the synthesis filters are combined to obtain the reconstructed signal $\hat{x}$(n). The reconstructed signal $\hat{x}(n)$ is different from the input signal $x(n)$ due to three errors: aliasing distortion (ALD), amplitude distortion (AMD), and phase distortion (PHD). While designing filters for the QMF bank, the main stress of most of the researchers has been on the elimination or minimization of the three distortions to obtain a perfect reconstruction (PR) or nearly perfect reconstruction (NPR) system. In several design methods reported [17–23], aliasing has been cancelled completely by selecting the synthesis filters cleverly in terms of the analysis filters and the PHD has been eliminated using the linear phase FIR filters. The overall transfer function of such an alias and phase distortion free system turns out to be a function of the filter tap coefficients of the lowpass analysis filter only, as the highpass and lowpass analysis filters are related to each other by the mirror image symmetry condition around the quadrature frequency $\pi/2$. Therefore, the AMD can be minimized by optimizing the filter tap weights of the lowpass analysis filter. If the characteristics of the lowpass analysis filter are assumed to be ideal in its passband and stopband regions, the PR condition of the alias and phase distortion free QMF bank is automatically satisfied in these regions, but not in the transition band. The objective function to be minimized is a linear combination of the reconstruction error in time domain and passband and stopband residual energy of the lowpass analysis filter of the filter bank .A nonlinear unconstrained optimization method [20] has been used to minimize the objective function by optimizing the coefficients of the lowpass analysis filter. A comparison of the design results of the proposed method with that of the already existing methods shows that this method is very effective in designing the two channel QMF bank, and gives an improved performance.

The organization of the paper is as follows: in Section 2, a relevant brief analysis of the QMF bank is given. Section 3 describes the formulation of the design problem to obtain the objective function. A mathematical formulation to minimize the objective function by using unconstrained optimization method has been explained in Section 4 and Section 5 presents the proposed design algorithm. In Section 6, two design examples (cases) are presented to illustrate the proposed design algorithm. Finally, an application of the proposed method in the area of subband coding of images is explained. A comparison of the simulation results of the proposed algorithm with that of the already existing methods is also discussed.

2. ANALYSIS OF THE TWO-CHANNEL QMF BANK

The *z*-transform of the output signal $\hat{x}(n)$, of the two channel QMF bank, can be written as [18–20, 23]

$$\hat{X}(z) = ½[H_0(z)F_0(z) + H_1(z)F_1(z)]X(z) + ½[H_0(-z)F_0(z) + H_1(-z)F_1(z)]X(-z). \quad (1)$$

Aliasing can be removed completely by defining the synthesis filters as given below [1, 20–23]

$$F_0(z) = H_1(-z) \text{ and } F_1(z) = -H_0(-z). \quad (2)$$

Therefore, using Eq. (2) and the relationship $H_1(z) = H_0(-z)$ between the mirror image filters, the expression for the alias free reconstructed signal can be written as

$$\hat{X}(z) = ½[H_0(z)H_1(-z) - H_1(z)H_0(-z)]X(z) = ½[H_0^2(z) - H_0^2(-z)]X(z) \quad (3)$$

or

$$\hat{X}(z) = T(z)X(z), \quad (4)$$

where *T (z)* is the overall system function of the alias free QMF bank, and is given by

$$T(z) = ½[H_0^2(z) - H_0^2(-z)] \quad (5)$$

To obtain perfect reconstruction, AMD (amplitude distortion) and PHD (phase distortion) should also be eliminated, which can be done if the reconstructed signal $\hat{x}(n)$ is simply made equal to a scaled and delayed version of the input signal *x(n)*. In that situation the overall system function, must be equal to:

$$T(z) = cz^{-(N-1)} \quad (6)$$

where (N-1) is reconstruction delay .The perfect reconstruction condition in time-domain can be expressed by using the convolution matrices as [20]

$$\begin{aligned}
&Bh_0 = m\\
&B = [d_1 + d_N, d_2 + d_{N-1}, ..., d_{N/2} + d_{N/2+1}]\\
&D = [d_1, d_2, ..., d_N]\\
&= 2\begin{bmatrix} h_0(1) & h_0(0) & 0 & \cdots & 0 \\ h_0(3) & h_0(2) & h_0(1) & h_0(0) & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ h_0(N-1) & h_0(N-2) & h_0(N-3) & \cdots & h_0(0) \end{bmatrix}\\
&h_0 = [h_0(0), h_0(1), ...h_0(N/2-1)]^T\\
&m = [0, 0, ...1]^T
\end{aligned} \quad (7)$$

Where $h_0(n)$, for n = 0, 1, 2. . . N/2-1, is the impulse response of filter H_0. To satisfy the linear phase FIR property, the impulse response $h_0(n)$ of the lowpass analysis filter can be assumed to be symmetric. Therefore,

$$h_0(n) = \begin{cases} h_0(N-1-n). \; 0 \le n \le N-1 \\ 0, n < 0 \text{ and } n \ge N \end{cases} \quad (8)$$

For real $h_0(n)$, $H_R(\omega)$ amplitude function is an even function of ω. Hence, by substituting Eqn. (8) into Eqn. (5), the overall frequency response of the QMF bank can be written as:

$$\mathrm{T}(\mathrm{e}^{j\omega}) = (\mathrm{e}^{-j\omega(N-1)}/2)[\left|H_0(e^{j\omega})\right|^2 - (-1)^{(N-1)}\left|H_0(e^{j(\pi-\omega)})\right|^2] \tag{9}$$

If the filter length, *N*, is odd, above equation gives $T(e^{j\omega}) = 0$ at $\omega = \pi/2$, implying severe amplitude distortion. In order to cancel the aliasing completely, the synthesis filters are related to the analysis filters by Eqn. (2) and $H_1(z) = H_0(-z)$. It means that the overall design task reduces to the determination of the filter tap coefficients of the linear phase FIR low-pass analysis filter $H_0(z)$ only, subject to the perfect reconstruction condition of Eqn. (7). Therefore, we propose to minimize the following objective function for the design of the QMF bank, by optimizing the filter tap weights of the lowpass filter $H_0(z)$

$$\Phi = \alpha_1 E_\mathrm{p} + \alpha_2 E_s + \beta E_r \tag{10}$$

where $\alpha_1, \alpha_2, \beta$ are real constants, E_p, E_s are the measures of passband and stopband error of the filter $H_0(z)$, and E_r is the square error of the overall transfer function of the QMF bank in time domain, respectively.

The square error E_r is given by

$$E_r = (Bh_0 - m)^T (Bh_0 - m) \tag{11}$$

3. PROBLEM FORMULATION

3.1. PASS-BAND ERROR

For even *N*, the frequency response of the lowpass filter $H_0(z)$ is given by

$$\mathrm{H}_0(\mathrm{e}^{j\omega}) = \mathrm{e}^{-j\omega(N-1)/2} \sum_{n=0}^{(N/2-1)} 2h_0(n)\cos(\omega(N-1)/2-n) \tag{12}$$

$$= \mathrm{e}^{-j\omega(N-1)/2} \sum_{n=0}^{(N/2-1)} b(n)\cos(\omega(N-1)/2-n) \tag{13}$$

$$= \mathrm{e}^{-j\omega(N-1)/2} H_R(\omega) \tag{14}$$

Where

$$b(n) = 2h_0(n) \tag{15}$$

and $H_R(\omega)$ is the magnitude function defined as

$$H_R(\omega) = \mathbf{b}^T\mathbf{c}. \tag{16}$$

Vectors **b** and **c** are

$$\mathrm{b} = [\mathrm{b}(0)\ \mathrm{b}(1)\ \mathrm{b}(2) \ldots \mathrm{b}(N/2-1)]^T$$

$$\mathrm{c} = [\cos\omega((N-1)/2)\ \ \cos\omega((N-1)/2-1)\ \ldots\ \cos(\omega/2)]^T$$

Mean square error in the passband may be taken as

$$E_p = (1/\pi)\int_0^{\omega_p} b^T(1-c)(1-c)^T b\,d\omega \tag{17}$$

$$= b^T Q b \tag{18}$$

where matrix Q is

$$Q = (1/\pi)\int_0^{\omega_p} (1-c)(1-c)^T d\omega \tag{19}$$

With (m, n) th element given by

$$q_{mn} = (1/\pi)\int_0^{\omega_p} [(1-\cos\omega(N-1)/2-m)(1-\cos\omega(N-1)/2-n)]d\omega \tag{20}$$

3.2 STOPBAND ERROR

Mean square error in the stopband may be taken as

$$E_s = (1/\pi)\int_{\omega_s}^{\pi} b^T cc^T bd\omega \qquad (21)$$

$$= b^T Pb \qquad (22)$$

where matrix **P** is

$$P = (1/\pi)\int_{\omega_s}^{\pi} cc^T d\omega \qquad (23)$$

With (m, n)th element given by

$$p_{mn} = (1/\pi)\int_{\omega_s}^{\pi} (\cos\omega(N-1)/2-m)(\cos\omega(N-1)/2-n)d\omega \qquad (24)$$

3.3 THE RECONSTRUCTION SQUARE ERROR

The square error E_r is given by

$$E_r = (Bh_0 - m)^T (Bh_0 - m) \qquad (25)$$

is used to approximate the prefect reconstruction condition in the time-domain in which **B** and m are all defined as in eqn.(7).

- **Minimization Of The Objective Function**

Using Eqs. (19), (23), and (26), the objective function Φ given by eqn. (11) can be written as

$$\Phi = \alpha_1 b^T Qb + \alpha_2 b^T Pb + \beta E_r$$

$$\Phi = 4\alpha_1 h_0{}^T Qh_0 + 4\alpha_2 h_0{}^T Ph_0 + \beta E_r \qquad (26)$$

It is in quadratic form without any constraints. Therefore the design problem is reduced to unconstrained optimization of the objective function as given in eqn. (26).

4. THE DESIGN ALGORITHM

In the designs proposed by Jain–Crochiere [9], and Swaminathan–Vaidyanathan [26], the unit energy constraint on the filter coefficients was also imposed. In the algorithm presented here, the unit energy constraint is imposed within some prespecified limit. The design algorithm proceeds through the following steps:

(1) Assume initial values of $\alpha_1, \alpha_2, \beta$, ϵ_1, ω_p, ω_s, and *N*.

(2) Start with an initial vector $\mathbf{h}_0 = [h_0(0)\ h_0(1)\ h_0(2)\ ...\ h_0((N/2)-1)]^T$; satisfying the unit energy constraint within a prespecified tolerance, i.e.

$$u = \left|1 - 2\sum_{k=0}^{N/2-1} h_0^2(k)\right| < \epsilon_1 \qquad (27)$$

(3) Set the function tolerance, convergence tolerance .

(4) Optimize objective function eqn. (26) using unconstrained optimization method for the specified tolerance.

(5) Evaluate all the component filters of QMF bank using h_0.

The performance of the proposed filter and filter bank is evaluated in terms of the following significant parameters:

Mean square error in the passband

$$E_p = (1/\pi)\int_0^{\omega_p} [|H_0(0)| - |H_0(f)|]^2 d\omega \qquad (28)$$

Mean square error in the stopband

$$E_s = \int_{\omega_s}^{\pi} \left| H_0(\omega) \right|^2 d\omega \tag{29}$$

stopband edge attenuation

$$A_s = -20\log_{10}(H_0(\omega_s)) \tag{30}$$

Measure of ripple

$$(\in) = \max_{\omega} \left| 10\log_{10} \left| T(\omega) \right| \right| - \min_{\omega} \left| 10\log_{10} \left| T(\omega) \right| \right| \tag{31}$$

5. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed technique for the design of QMF bank has been implemented in MATLAB. Two design cases are presented to illustrate the effectiveness of the proposed algorithm. The method starts by initializing value of the filter coefficients $h_0(n)$ to zero for all n, except that $h_0(N/2-1) = h_0(N/2) = 2^{-1/2}$, $0 \le n \le N-1$ and using half of its coefficients which **t**hen be solved using unconstrained optimization (interior reflective Newton method) problem. With this choice of the initial value of the filter coefficients, the unit energy constraint is satisfied.

In both designs, stopband first lobe attenuation (A_s) has been obtained and the constants $\alpha_1, \alpha_2, \beta$, $\square_1$ have been selected by trial and error method to obtain the best possible results. The parameters used in the two designs, which will be referred to as Cases 1 and 2, are N =24, α_1 =.01, α_2 =0.1, β =.00086,function$_{tolerance}$=1e-6,X$_{tolerance}$=1e-8, $\square_1$ = 0.15, (IT) =38 ω_p = 0.4π, ω_s = 0.6π, tau = 0.5, and ***N*** = 32, α_1 =.1, α_2 =0.1, β =.00086,function$_{tolerance}$=1e-6, X$_{tolerance}$=1e-8, $\square_1$ = 1e-8, ω_p = 0.4π, ω_s = 0.6π,tau = 0.5, respectively. For comparison purposes the method of Chen and Lee [8] was applied to design the QMF banks with parameters specified above and using the same initial **h**, as by the proposed method to both the design examples (cases) respectively. The comparisons are made in terms of phase response, passband energy, stopband energy, stopband attenuation and peak ripple $(\in)$.

Case 1

For N = 24, ωp = 0.4π, ωs = 0.6π, α1 = .1, α2 =.1, $\square_1$ = 0.15, β = 1, the following filter coefficients for $(0 \le n \le N/2-1)$ are obtained

h_0 (n) = [-0.0087 -0.0119 0.0094 0.0221 -0.0123 -0.0332 0.0235 0.0540 -0.0463 -0.0970 0.1356 0.4623]

The corresponding normalized magnitude plots of the analysis filters $H_0(z)$ and $H_1(z)$ are shown in Figure 2a & 2c. Figure 2e shows the reconstruction error of the QMF bank (in dB). The significant parameters obtained are: Ep = .1438, Es = 1.042×10−6, As = 4**5.831 dB** and $(\in)$ = **0.9655.**

Case 2

For N = 32, ω_p = 0.4π, ω_s = 0.6π, α_1 = 0.*1*, α_2 = 0.*1*, ε_1 = 0.15, β = 0.00086, the following filter coefficients for $(0 \le n \le N/2-1)$ are obtained

h_0 (n) = [-0.0034 -0.0061 0.0020 0.0104 -0.0021 -0.0154 0.0050 0.0237 -0.0102 -0.0349 0.0218 0.0549 -0.0460 -0.0987 0.1343 0.4628]

The corresponding normalized magnitude plots of the analysis filters H_0 *(z)* and H_1 *(z)* are shown in Fig. 2b & 2d. Figure 2f shows the reconstruction error of the QMF bank (in dB). The significant parameters obtained are: Ep = .0398, Es = 2.69×10−7, As = **53.391** dB, and $(\in)$ = **0.27325**.

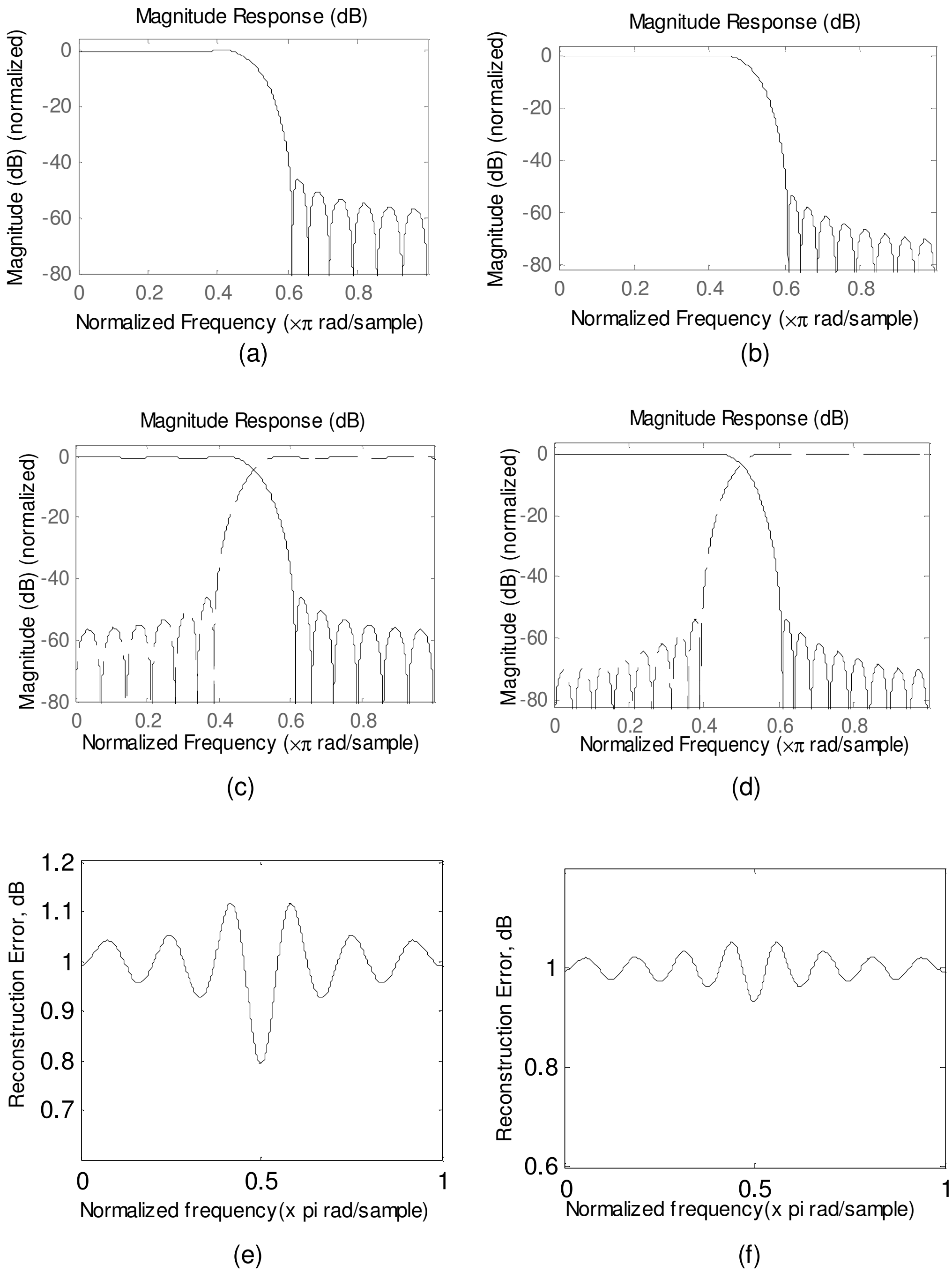

FIGURE 2: (a) Amplitude response of the prototype analysis filters for $N = 24$. (b) Amplitude response of the prototype analysis filters for N=32(c) Magnitude response of overall filter bank N=24 (d) Magnitude response of overall filter bank N=32 (e) Reconstruction error for overall filter bank (N=24) in dB (f) Reconstruction error for overall filter bank (N=32) in dB

The simulation results of the proposed method are compared with the methods of Jain–Crochiere design [9],Gradient method [26], Chen–Lee [8], Lu–Xu–Antoniou [10], Xu–Lu–Antoniou [21], [22], Sahu O.P. and Soni M.K[17], General-purpose [24], and Smith–Barnwell [15], for $N = 32$, and are summarized in Table 1. The results indicate that the performance of our proposed method is much better than all the considered methods in terms of A*s*. The proposed method also gives improved performance than General Purpose and Smith–Barnwell, methods in terms of *Ep*, than Jain–Crochiere, Gradient,Chen–Lee, Lu–Xu–Antoniou, and Xu–Lu–Antoniou methods in terms of Es, and than General-purpose and Smith–Barnwell methods in terms of linearity of the phase response.

Methods	*E*p	*E*s	*A*s (dB)	$(\in)$ (dB)	Phase response
Jain–Crochiere [9]	2.30× 10−8	1.50×10−6	33	0.015	Linear
Gradient method [26]	2.64× 10−8	3.30×10−6	33.6	0.009	Linear
General purpose [24]	0.155	6.54×10−8	49.2	0.016	Nonlinear
Smith–Barnwell [15]	0.2	1.05×10−6	39	0.019	Nonlinear
Chen–Lee [8]	2.11× 10−8	1.55×10−6	34	0.016	Linear
Lu–Xu–Antoniou [21]	1.50× 10−8	1.54×10−6	35	0.015	Linear
Xu–Lu–Antoniou [22]	3.50× 10−8	5.71×10−6	35	0.031	Linear
Sahu O.P,Soni M.K[17]	1.45× 10−8	2.76×10−6	33.913	0.0269	Linear
Proposed method	.0398	2.69×10−7	53.391	.2732	Linear

TABLE 1: Comparison of the proposed method with other existing methods based on significant parameters for N=32

According to the results obtained, some observations about filter characteristics can be made. The frequency response of H_0 for 16, 24 32 taps prototype filter shown in Figure 2. The effect of the parameter N is clearly seen on the stopband attenuation and reconstruction error of the QMF bank from the figure. Hence, longer prototype filter leads to better stopband attenuation, and better performance. As the maximum overall ripple for QMF bank decreases with increase in the length of prototype filter upto N=32. It can be noted that as the length increased to 64 there is a slight dip in the frequency response characteristic of the prototype filter which deteriorates the overall performance of the QMF bank.

5.1 APPLICATION TO SUBBAND CODING OF IMAGES

In order to assess performance of the linear phase PR QMF banks, the designed filter banks were applied for the subband coding of 256x256, and 512x512 Cameraman, Mandrill and Lena images. The criteria of comparison used is objective and subjective performance of the encoded images. Influence of certain filter characteristics, such as stopband attenuation, maximum overall ripple, and filter length on the performance of the encoded images is also investigated.

A common measure of encoded image quality is the peak signal-to-noise ratio, which is given as:

$$PSNR = 20\log_{10}(255/\sqrt{MSE}) \tag{32}$$

where *MSE* denotes the mean-squared-error

$$MSE = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}\left[I(x,y) - I'(x,y)\right]^2 \tag{33}$$

where, M,N are the dimensions of the image and $I(x,y)$, $I'(x,y)$ the original and reconstructed image respectively.

In general, for satisfactory reconstruction of original image, MSE must be lower, while PSNR must be high. The results of encoded Cameraman, Mandrill and Lena images are shown in figure 3. For Cameraman, Mandrill and Lena images, the best filters in sense of rate-distortion performance are QMF banks with prototype filter length greater than 16. The results obtained show that linear phase PR QMF banks are quite competitive to the best known biorthogonal filters for image coding with respect to PSNR performance for Cameraman, Mandrill and Lena images. PSNR for all three types of images increase considerably for the filter length greater than 16. The lower length affects cameraman image more as compared to other two images. Making experiments with QMF banks with the same length prototype filter and different frequency responses, filters with better stopband attenuation perform better PSNR performance.

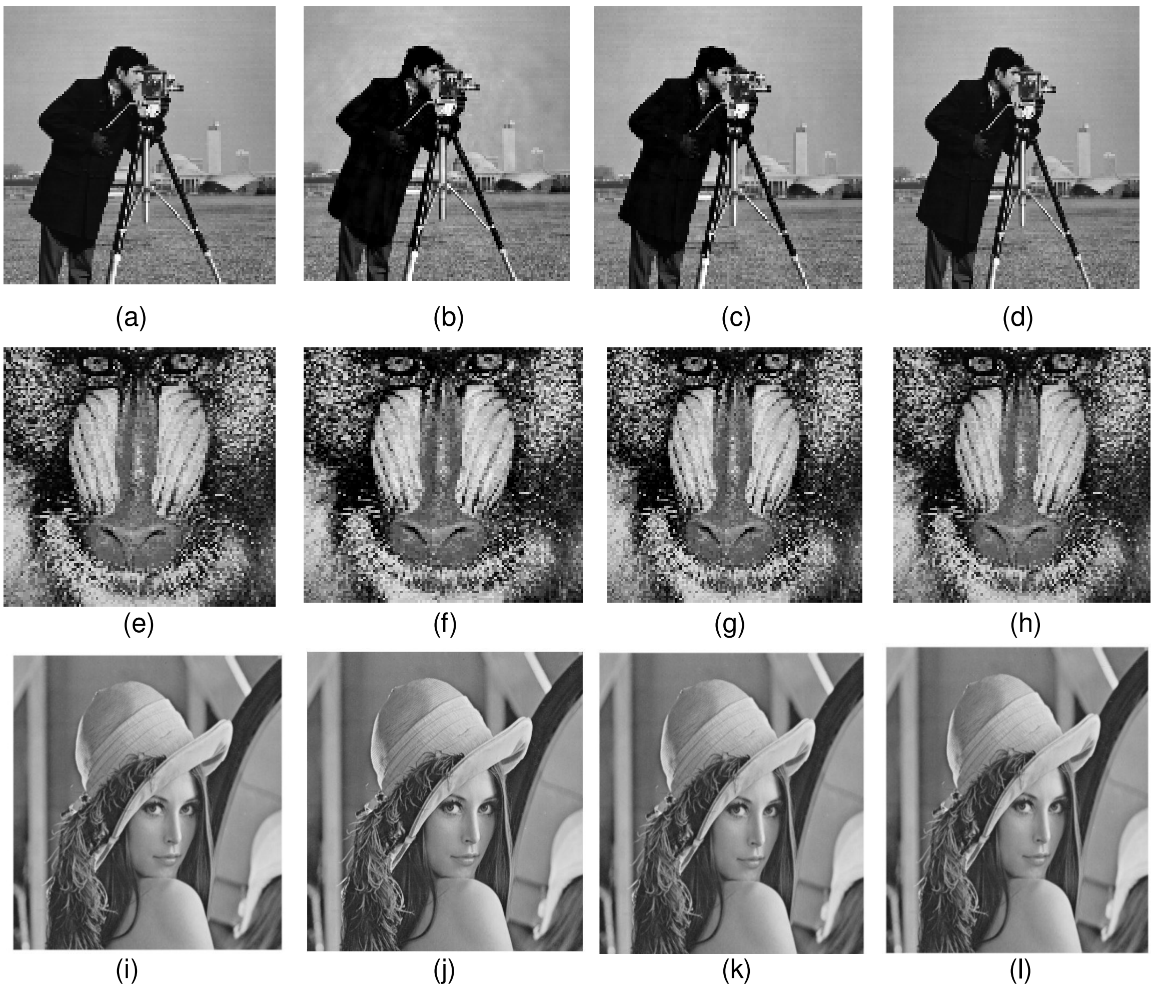

FIGURE 3: Subband coding of images using designed filter of length N (a) original cameraman image (b) reconstructed cameraman image for *N*=24 (c) reconstructed cameraman image N=32 (d) reconstructed cameraman image *N*=64 (e) original mandrill image (f) reconstructed mandrill image N=24 (g) reconstructed mandrill image N=32 (h) reconstructed mandrill image N=64 (i) original Lena image (j) reconstructed Lena image N=24 (k) reconstructed Lena image N=32 (l) reconstructed Lena image N=64

In addition to quantitative PSNR comparison, the reconstructed images were evaluated to assess the perceptual quality. For QMF banks, the perceptual quality of the image improves with the increasing length of the prototype filter h_0. This is especially obvious for the filter length above 16. The quality of encoded images obtained with QMF banks are very close to the quality of the original image. As we have been expecting, in our experiments, the most disturbing visual artifact was ringing. At lower length, this type of error affect the quality of reconstructed images significantly. The results shown in the table 2 are for single level decomposition. As the level of decomposition increases the PSNR for the Cameraman image is reduced from approximately 86 (N=24) to 75. Further, as the length increased greater than 32, complexity increased and for filter length 64 the images become brighter and the both objective and subjective performance of the images deteriorates. Thus the filter of length 24 or 32 may be used for satisfactory performance both in terms of least MSE as well as highest PSNR.

Length of prototype filter	Stop band edge	Max overall ripple dB	Stop band attenuation dB	PSNR			MSE		
				Cameraman	Mandrill	Lena	Cameraman	Mandrill	Lena
8	0.31425	8.90863	34.7831	-12	------	------	1.24e6	---	-----
12	0.309	5.80215	37.1274	52.7497	52.3128	52.8201	0.3452	0.3818	0.3397
24	0.30375	1.0089	45.8315	86.2702	83.2169	87.4151	1.5e-4	3.1e-4	1.17e-4
32	0.3025	0.30769	53.3916	89.8796	88.4642	90.2282	6.6e-5	9.26e-5	6.16e-5
64	………	0.11733	--------	53.2733	50.0073	54.3468	0.3060	0.6492	0.2390

TABLE 2: Performance results of designed QMF banks on image coding

6. CONCLUSIONS

In this paper, a modified technique has been proposed for the design of QMF bank. The proposed method optimizes the prototype filter response characteristics in passband, stopband and also the square error of the overall transfer function of the QMF bank. The method has been developed and simulated with the help of MATLAB and two design cases have been presented to illustrate the effectiveness of the proposed method. A comparison of the simulation results indicates that the proposed method gives an overall improved performance than the already existing methods, as shown in Table 1, and is very effective in designing the quadrature mirror filter banks.

We have also investigated the use of linear phase PR QMF banks for subband image coding. Coding experiments conducted on image data indicate that QMF banks are competitive with the best biorthogonal filters for image coding. The influence of certain filter characteristics on the performance of the encoded image is also analysed. It has been verified that filters with better stopband attenuation perform better rate-distortion performance. Ringing effects can be avoided by compromising between the stopband attenuation and filter length. Experimental results show that 24 and 32 taps filter is the best choice in sense of objective and subjective performances.

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