Analysis of the Effects of the Frequency Band Values on the Performance of the Cosine Modulated Filter Bank Design

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ABSTRACT:
In this study, 16-channel cosine modulated filter bank is designed. In the proposed design, the coefficients of the prototype low-pass Finite Impulse Response filter with an N=64 filter order is optimized using Artificial Bee Colony Algorithm. In the presented study, different design examples are given with different frequency band values. Amplitude response error and transition band error values are obtained for each design examples. Via these examples, the effects of the change in transition and stopband frequencies on the performance of the designed filter bank is investigated. Simulation results show that determining frequency band values of prototype filter properly improves the performance of the filter bank and decreases the amplitude response error and transition band error values.

KEYWORDS: ABC Algorithm, Cosine modulated filter bank, Pass-band frequency, Stop-band frequency.

1. INTRODUCTION

Filter banks are widely used in many modern engineering fields such as communication, data (audio, image, video) processing, digital audio and multimedia, multi-carrier modulators and biomedical signal processing since the less computational complexity and the reduced cost [1]. An efficient way of designing filter banks is modulated filter banks. In the modulated filter banks, instead of designing each filter individually in the analysis and synthesis parts, a prototype filter is designed and all other sub-band filters are obtained by applying prototype filter discrete transforms. One of the most popular modulated filter banks in the literature is the Cosine Modulated Filter Banks (CMFBs) because of its ease of design and application and its real valued nature [2]. The idea of CMFB was proposed by different working groups independently [3-7]. There are lots of different approaches developed for the optimal design of CMFBs in the literature [8]. One of the most preferred of these methods is the CMFB designs using heuristic algorithms. Heuristic algorithm based CMFB designs are reviewed in [9]. In these studies, Genetic Algorithm (GA), Particle Swarm Optimization (PSO) Algorithm and so on many heuristic methods and their variants were used in the design of CMFBs with different optimization problems.

In this study, a 16-channel cosine modulated filter bank is designed using Artificial Bee Colony (ABC) Algorithm. Via two design examples, the effects of the change in transition and stopband frequencies on the performance of the designed CMFB is investigated. The following sections of the study are organized as follows: In the second section, filter bank and CMFB theory is introduced. In the third section, ABC algorithm is shortly explained. Design examples are included in the fourth section. The fifth section is the conclusion part.

2. FILTER BANK THEORY

A filter bank is a sequence of filters that allows a signal to be transmitted by separating the desired number of sub-bands. These filters can be low-pass, band-pass, or high-pass. In a filter bank, the part where the input signal is sampled-down and divided into sub-bands is called as the *analysis bank*; the part which the sub-sampled data is interpolated and combined to obtain the resultant input signal is called as the *synthesis bank*. Block diagram of the common structure of filter banks is shown in Figure 1.

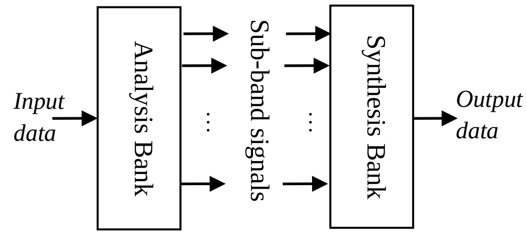
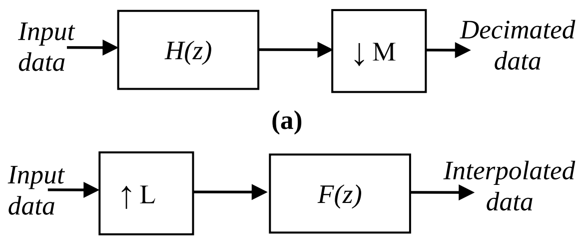


Fig. 1. Block diagram of the CMFB.

An M-channel filter bank consists of consecutive (cascade) connected decimator and interpolator structures. An M-fold decimator performs M-fold down-sampling after limiting the frequency band of original data to π/M to avoid overlapping between sub-channels. An L-fold interpolator adds L-1 zeros between two consecutive samples of the input data and after than interpolates these values. Figure 1 shows block diagrams of decimator and interpolator structures where *H(z)* is the anti-aliasing filter and *F(z)* is the anti-imaging filter [10]:



(a)

(b)

Fig. 2. **(a)** M-fold decimator block diagram, **(b)** L-fold interpolator block diagram.

2.1. Cosine Modulated Filter Bank

In this type of filter bank, the prototype filter is firstly designed. All other analysis and synthesis filters of the CMFB are Discrete Cosine Transform (DCT) - applied versions of the prototype filter. So, the design of CMFB is reduced to a prototype design and a DCT. The CMFB analysis and synthesis bank equations are given by equation 1 and 2:

$$h_k(n) = 2.h(n).\cos\left[(2k+1)\frac{\pi}{2M}\left(n-\frac{N}{2}\right)+(-1)^k\,\frac{\pi}{4}\right] \quad (1)$$

$$f_k(n) = 2.h(n).\cos\left[(2k+1)\frac{\pi}{2M}\left(n-\frac{N}{2}\right)-(-1)^k\,\frac{\pi}{4}\right] \quad (2)$$

$$0 \le n \le N-1$$

$$0 \le k \le M-1$$

where $h_k(n)$ is the analysis filter, $f_k(n)$ is the *synthesis filter*, *h(n)* is the *coefficients of the prototype filter's impulse response*, *M* is the *number of the channels*, *N-1* is the *filter order*, *N* is *filter length* [9, 10].

3. ARTIFICIAL BEE COLONY ALGORITHM

ABC algorithm is a swarm-based heuristic algorithm proposed by Karaboga in 2005 [11]. The algorithm is modeled by inspiration from the intelligent behaviors of honey bees which they exhibit when looking for food [12]. Two basic concepts that make the behavior of the bees intelligent are defined as self-organization and work sharing by Karaboga [11]. There are three type of bees in the standard ABC algorithm: employed bees, onlooker bees and scout bees. The three phases of the algorithm named from these bees: employed bee phase, onlooker bee phase, scout phase. Initially, each possible solution of the problem represents a food source. All food sources are evaluated and each possible solution is tried to be improved. Employed bees determine a new food source in the neighborhood of the previously found source and memorize the new source if it's better than the previous one. Onlooker bees wait in the hive and when they are assigned, search the food sources on the basis of the information received by the employed bees. An employed bee turns into a scout when the nectar at the source is exhausted. Scout bees move randomly in the search space. The flowchart of the ABC algorithm is given in Figure 3 which includes some information about the phases of the ABC algorithm:

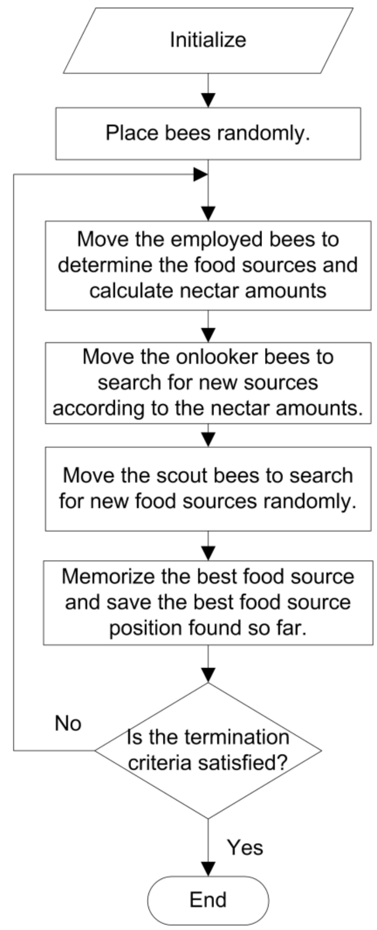


Fig. 3. Flowchart of the ABC algorithm.

4. DESIGN EXAMPLES

In this study, we first designed a 16-channel filter bank using the ABC algorithm. There are different CMFB designs in the literature ranging from 2 channels to M channels [13, 14]. Then, two different design examples were determined and the effect of the frequency band values of the prototype filter on the design of the filter bank was investigated. ABC control parameter values used for both design examples are given in Table I.

Table I. ABC Algorithm control parameter values for the design examples.

Control Parameter	Parameter Value
Population Size	20
Limit	100
Max.Number of Iterations	100

Error in amplitude response of filter bank is given with following equation [15, 16]:

$$e_{am} = \max\left(1 - \left|T_0(e^{jw})\right|\right) \qquad (3)$$

where $T_0(e^{jw})$ is the distortion transfer function Transition band error is given as [17]:

$$\phi_t = \left(H_0(\omega) - 0.707\, H_0(0)\right)^2,\ \omega = \omega_c \qquad (4)$$

where H_0 is the transfer function of the prototype filter of CMFB and w_c is the cut off frequency which equals to $(w_p+w_s)/2$.

The Mean Square Error (MSE) value in is given as:

$$MSE = \frac{1}{M}\sum_{n=0}^{M-1}[x(n) - \tilde{x}(n)]^2 \qquad (5)$$

where $x(n)$ is the input signal and $\tilde{x}(n)$ is the filtered input signal obtained at the output of the filter.

4.1. Design Example 1

In the first example, designed CMFB values were determined as follows:

- Filter Order : N=64
- Passband edge frequency : w_p=0.01
- Stopband edge frequency : w_s=0.015
- Number of channels : M=16

The obtained results of the CMFB designed according to the above statements are:

- $\phi_t = 0.1191$
- $e_{am} = 0.3257$

The amplitude response of the prototype filter of the CMFB designed in Example 1 and the frequency response of the analysis filter for the two-channel CMFB are shown in Figures 4 and 5, respectively.

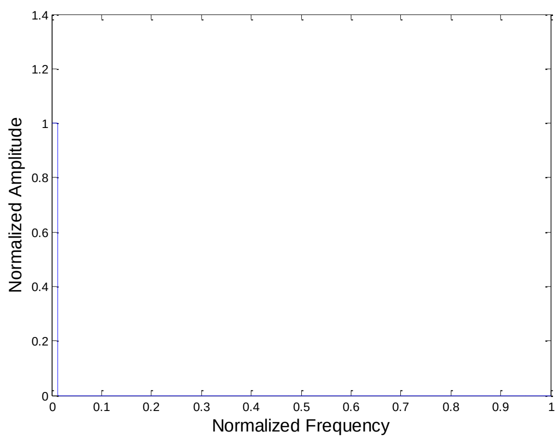


Fig. 4. Normalized amplitude response of the prototype filter for Example 1.

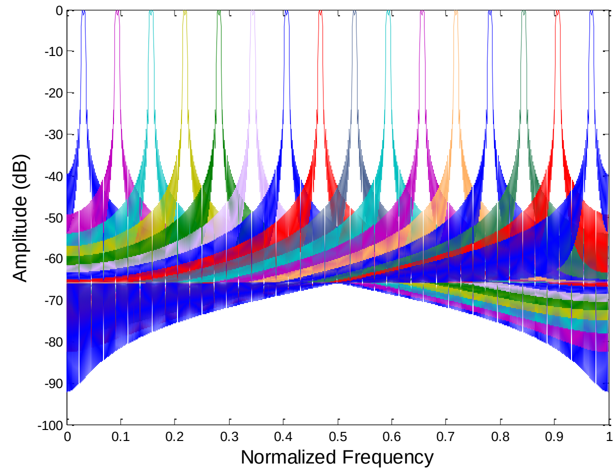


Fig. 5. Magnitude responses of analysis filters for Design Example 1.

Figure 6 shows convergence graph of ABC Algorithm for Design Example 1.

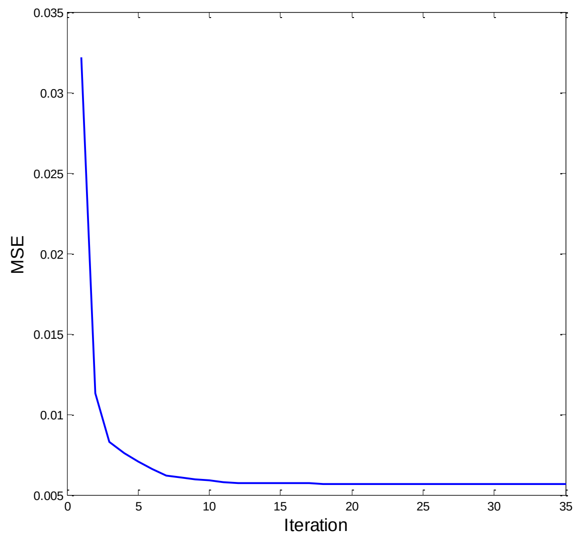


Fig. 6. Convergence graph of ABC algorithm for Design Example 1.

4.2. Design Example 2

In the second example, all design criteria except the frequency values are the same as the 'Design Example 1'. Designed CMFB values were defined as follows.

- Filter Order : N=64
- Passband edge frequency : w_p=0.02
- Stopband edge frequency : w_s=0.03
- Number of channels : M=16

The obtained results of the CMFB designed according to the above statements are:

- $\phi_t = 0.0595$
- $e_{am} = 0.1452$

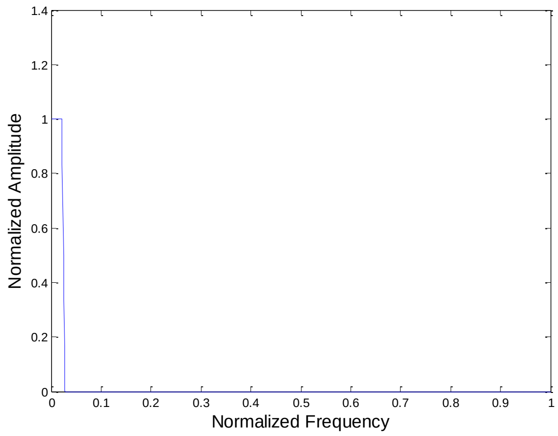


Fig. 7. Normalized amplitude response of the prototype filter for Example 2.

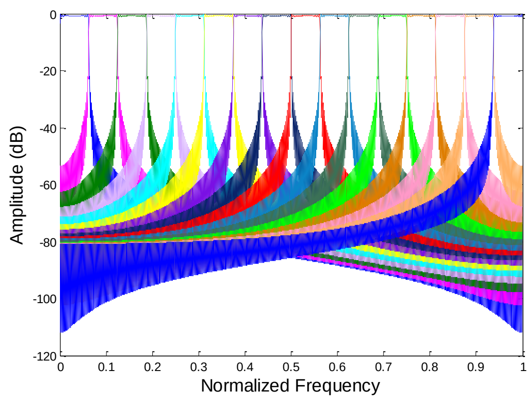


Fig. 8. Magnitude responses of analysis filters for Design Example 2.

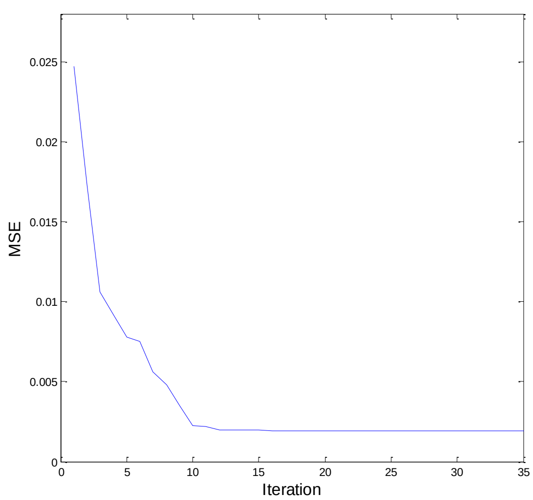


Fig. 9. Convergence graph of ABC algorithm for Design Example 2.

The amplitude response of the prototype filter of the CMFB designed in Example 2 and the frequency response of the analysis filter for the two-channel CMFB are shown in Figures 7 and 8, respectively. Figure 9 shows convergence graph of ABC Algorithm for Example 2.

5. CONCLUSION

In this study, a 16-channel 64th order cosine modulated filter bank has been designed. Prototip filter coefficients of filter bank are optimized using a swarm-based meta-heuristic ABC Algorithm. Two different design examples have been determined to investigate the frequency band values effects on performance of filter bank. Transition band error (ϕ_t) is 0,1191 in the first example and 0,0595 in the second one. Error in amplitude response (e_{am}) is 0,3257 in the first example and 0,1452 in the second one. The simulation results show that, both error values is decreased in Example 2. The frequency band values selected in a very small range lead to inefficient use of the frequency spectrum of the filter bank. As a result, the improperly selected frequency band values in the first example are improved in the second example and obtained error values are decreased.

REFERENCES

[1] P. P. Vaidyanathan, **"Multirate systems and filter banks"**, *Prentice-Hall*, Inc., 1993.

[2] A. Mertins, **"Signal Analysis: Wavelets, Filter Banks, Time-Frequency Transforms, and Applications ",** *England.: Wiley*, 1999.

[3] H. S. Malvar, **"Modulated Qmf Filter Banks with Perfect Reconstruction",** *Electronics Letters*, Vol. 26, pp. 906-907, Jun 21 1990.

[4] H. S. Malvar, **"Extended Lapped Transforms - Properties, Applications, and Fast Algorithms ",** *Ieee Transactions on Signal Processing*, Vol. 40, pp. 2703-2714, Nov 1992.

[5] T. A. Ramstad and J. P. Tanem, **"Cosine-Modulated Analysis-Synthesis Filterbank with Critical Sampling and Perfect Reconstruction ",** *Icassp 91*, Vols. 1-5, pp. 1789-1792, 1991.

[6] R. D. Koilpillai and P. P. Vaidyanathan, **"New Results on Cosine-Modulated Fir Filter Banks Satisfying Perfect Reconstruction ",** *Icassp 91*, Vols. 1-5, pp. 1793-1796, 1991.

[7] R. D. Koilpillai and P. P. Vaidyanathan, **"Cosine-Modulated Fir Filter Banks Satisfying Perfect Reconstruction ",** *Ieee Transactions on Signal Processing*, vol. 40, pp. 770-783, Apr 1992.

[8] K. Shaeen, E. Elias, **"Prototype Filter Design Approaches for Near Perfect Reconstruction Cosine Modulated Filter Banks - A Review",** *Journal of Signal Processing Systems for Signal Image and Video Technology*, Vol. 81, pp. 183-195, Nov 2015.

[9] G. Ozdemir, N. Karaboga, **"A Review on the Meta-Heuristic Optimization Algorithms for Cosine**

Modulated Filter Banks", *Artificial Intelligence Review,* pp. 1-25, 2017.

[10] L. Milic, **"Multirate Filtering for Digital Signal Processing: MATLAB Applications ",** *Information Science Reference - IGI Publishing*, 2009.

[11] D. Karaboga, **"An Idea Based on Honey Bee Swarm for Numerical Optimization",** *Technical Report-tr06, Erciyes University, Engineering Faculty, Computer Engineering Department,* 2005.

[12] D. Karaboga, **"Artificial bee colony algorithm",** *Scholarpedia,* Vol. 5, pp. 6915, 2010.

[13] G. Ozdemir, N. Karaboga, and T. Koza, **"Performance Comparison of Two Channel CMFB and QMF Bank Designed via ABC Algorithm",** *2017 25th Signal Processing and Communications Applications Conference (Siu),* 2017.

[14] H. Liu, Z. Yang, and Z. Cao, **"Design perfect reconstruction cosine-modulated filter bank by variable neighbourhood search-least-mean-square error",** *Iet Signal Processing,* Vol. 6, pp. 273-280, May 2012.

[15] B. Kuldeep, A. Kumar, and G. K. Singh, **"PSO based optimized fractional derivative constraints for designing M-Channel filter bank",** in *Signal Processing, Computing and Control (ISPCC), 2015 International Conference on*, 2015, pp. 140-144.

[16] C. D. Creusere and S. K. Mitra, **"A Simple Method for Designing High-Quality Prototype Filters for M-Band Pseudo Qmf Banks",** *Ieee Transactions on Signal Processing,* Vol. 43, pp. 1005-1007, Apr 1995.

[17] B. Kuldeep, A. Kumar, and G. K. Singh, **"Design of Multi-channel Cosine-Modulated Filter Bank Based on Fractional Derivative Constraints Using Cuckoo Search Algorithm ",** *Circuits Systems and Signal Processing,* Vol. 34, pp. 3325-3351, Oct 2015.