Journal of Advanced Research (2015) 6, 839–849

Cairo University

Journal of Advanced Research

ORIGINAL ARTICLE

Non-uniform cosine modulated filter banks using meta-heuristic algorithms in CSD space

Shaeen Kalathil *, **Elizabeth Elias**

Department of Electronics and Communication Engineering, National Institute of Technology Calicut, Kerala, India

A R T I C L E   I N F O

Article history:
Received 26 May 2014
Received in revised form 27 June 2014
Accepted 30 June 2014
Available online 6 July 2014

Keywords:
Cosine modulation
Non-uniform filter banks
Artificial Bee Colony algorithm
Gravitational Search algorithm
Harmony Search algorithm

A B S T R A C T

This paper presents an efficient design of non-uniform cosine modulated filter banks (CMFB) using canonic signed digit (CSD) coefficients. CMFB has got an easy and efficient design approach. Non-uniform decomposition can be easily obtained by merging the appropriate filters of a uniform filter bank. Only the prototype filter needs to be designed and optimized. In this paper, the prototype filter is designed using window method, weighted Chebyshev approximation and weighted constrained least square approximation. The coefficients are quantized into CSD, using a look-up-table. The finite precision CSD rounding, deteriorates the filter bank performances. The performances of the filter bank are improved using suitably modified meta-heuristic algorithms. The different meta-heuristic algorithms which are modified and used in this paper are Artificial Bee Colony algorithm, Gravitational Search algorithm, Harmony Search algorithm and Genetic algorithm and they result in filter banks with less implementation complexity, power consumption and area requirements when compared with those of the conventional continuous coefficient non-uniform CMFB.

Introduction

Filter banks are extensively used in different applications such as compression of speech, image, video and audio data, transmultiplexers, multi carrier modulators, adaptive and bio signal processing [1]. Filter banks decompose the spectrum of a given signal into different subbands and each subband is associated with a specific frequency interval. In certain applications such as wireless communications and subband adaptive filtering, a non-uniform decomposition of subbands is preferred [2–5].

Design of filter banks with good frequency response characteristics and reduced implementation complexity is highly desired in different applications. Multipliers are the most expensive components for implementing the digital filter in hardware. The multipliers in the filters can be implemented using shifters and adders, if the coefficients are represented by signed power of two (SPT) terms [6]. Canonic signed digit (CSD) representation is a special case of SPT representation [7]. It contains minimum number of SPT terms and the adjacent digits will never be both non-zeros. As a result, efficient implementation of multipliers using shifters/adders is possible [7].

Different methods exist for the design of non-uniform filter banks (NUFB). In one approach, two channel filter banks are used as building blocks and a tree structured filter bank is generated for getting non-uniform band splitting [1]. In the second approach, one or more prototype filters are designed and all the other filters are obtained by cosine or DFT modulation [8–10]. In another approach, called recombination technique, the analysis filters of an M channel uniform filter bank are

* Corresponding author. Tel.: +91 9447100244; fax: +91 4952287250.
E-mail address: shaeen_k@yahoo.com (S. Kalathil).

Peer review under responsibility of Cairo University.

Production and hosting by Elsevier

2090-1232 © 2014 Production and hosting by Elsevier B.V. on behalf of Cairo University.
http://dx.doi.org/10.1016/j.jare.2014.06.008

combined with the synthesis filters of a different filter bank having smaller number of channels [11].

A simple and efficient design of NUFB is by the cosine modulation of the prototype filter and combining appropriate filters of the resulting uniform filter bank [10]. The non-uniform CMFB design is derived from a uniform CMFB. Hence the attractive properties of a uniform CMFB are retained in the non-uniform CMFB. Only the prototype filter need to be designed and optimized. All the other analysis and synthesis filters with unequal bandwidths are obtained from this filter, by merging appropriate filters of the uniform filter bank. The prototype filter is designed using non-linear optimization in [10]. A modified approach, in which the prototype filter is designed using linear search technique was given in Zijing and Yun [12].

Cosine modulated filter banks (CMFB) are one popular class among the different M-channel maximally decimated filter banks [13–15]. In perfect reconstruction (PR) filter banks, the output will be a weighted delayed replica of the input. In case of near perfect reconstruction (NPR) filter banks, a tolerable amount of aliasing and amplitude distortion errors are permitted. Design of NPR CMFB is easier and less time consuming compared to the corresponding PR CMFB. Even though small amounts of aliasing and amplitude distortion errors exist, these filter banks are widely used in different applications due to the design ease [16–19]. It is difficult to attain high stopband attenuation with PR CMFB. Hence as a compromise, NPR structures can be preferred in those applications, where some aliasing can be tolerated.

In multiplier-less filter banks, the filter coefficients are represented by signed power of two terms (SPT) and the multiplications can be carried out as additions, subtractions and shifting. Canonic signed digit (CSD) representation is a special form of SPT representations and is a minimal one. But CSD representation of the coefficients may lead to deterioration of the filter performances. Hence suitable optimization techniques have to be deployed to improve the performances. Multiplier-less design of NPR non-uniform CMFB with conventional FIR filter as the prototype filter and the coefficients synthesized in the CSD form using modified meta-heuristic algorithms is hitherto not reported in the literature.

In this paper a new approach for the design of multiplier-less NPR non-uniform CMFB is given, in which the prototype filter is designed using different techniques such as window method, weighted Chebyshev approximation and weighted constrained least square method. The coefficients are quantized using canonic signed digit (CSD) representation. The CSD rounding deteriorates the filter bank performances. The finite precision performances of the filter bank in the CSD space can be made at par with those of infinite precision, using various modified meta-heuristic algorithms. To improve the frequency response characteristics of the filters, optimization in the discrete domain is required. Conventional gradient based approaches cannot be deployed here, as the search space is discrete. Meta-heuristic algorithm is a proper choice for such problems [20] to result in global solutions by properly tuning the parameters.

The remaining part of the paper is organized as follows: Section ‘Cosine modulated uniform filter banks’ gives an introduction of NPR CMFB. Section ‘Cosine modulated non-uniform filter banks’ briefly illustrates the design of non-uniform NPR CMFB. Section ‘Design of prototype filter’ gives a brief description of the different prototype filter designs for the NPR CMFB. Section ‘Multiplier-less design of non-uniform CMFB’ explains the design of CSD coefficient CMFB. Section ‘Optimization of non-uniform CMFB using modified meta-heuristic algorithms’ outlines the optimization of the CSD coefficient filter bank using various modified meta-heuristic algorithms. Result analysis is given in Section ‘Results and discussion’ and the conclusion in Section ‘Conclusion’.

Cosine modulated uniform filter banks

In an M-channel maximally decimated uniform CMFB, the input signal is decomposed into subband signals having equal bandwidths. A set of M analysis filters $H_k(z),\ 0 \leqslant k \leqslant M-1$ decomposes the input signal into M subbands, which are in turn decimated by M fold downsamplers. A set of synthesis filters $F_k(z),\ 0 \leqslant k \leqslant M-1$ combines the M subband signals after interpolation by a factor of M on each channel. The reconstructed output, $Y(z)$ is given by Eq. (1) [1].

$$Y(z) = T_0(z)X(z) + \sum_{l=1}^{M-1} T_l(z)X(ze^{-j2\pi l/M}) \tag{1}$$

where $T_0(z)$ is the distortion transfer function and $T_l(z)$ is the aliasing transfer function.

$$T_0(z) = \frac{1}{M}\sum_{k=0}^{M-1} F_k(z)H_k(z) \tag{2}$$

$$T_l(z) = \frac{1}{M}\sum_{k=0}^{M-1} F_k(z)H_k(ze^{-j2\pi l/M}) \tag{3}$$

$l = 1, 2, \ldots, M-1$

The analysis and synthesis filter responses are normalized to unity. Hence as given in Koilpillai and Vaidyanathan [21]

$$(1-\delta_1) \leqslant |MT_0(e^{j\omega})| \leqslant (1+\delta_2) \tag{4}$$

Amplitude distortion error is given by

$$E_r = \max_{\omega}|[|MT_0(e^{j\omega})| - 1]| \tag{5}$$

The worst case aliasing distortion is given by

$$E_a = \max_{\omega}(T_{alias}(\omega)) \tag{6}$$

where

$$T_{alias}(\omega) = \left[\sum_{l=1}^{M-1}|T_l(e^{j\omega})|^2\right]^{\frac{1}{2}} \tag{7}$$

For the design of NPR CMFB, a linear phase FIR filter with good stopband attenuation and which provides flat amplitude distortion function is initially designed. All the analysis and synthesis filters are generated from this prototype filter by cosine modulation. All the coefficients are real. The coefficients of the analysis and synthesis filters are given by Eqs. (8) and (9) respectively [1].

$$h_k(n) = 2p_0(n)\cos\left(\frac{\pi}{M}(k+0.5)\left(n-\frac{N}{2}\right) + (-1)^k\frac{\pi}{4}\right) \tag{8}$$

$$f_k(n) = 2p_0(n)\cos\left(\frac{\pi}{M}(k+0.5)\left(n-\frac{N}{2}\right) - (-1)^k\frac{\pi}{4}\right) \tag{9}$$

$k = 0, 1, 2, \ldots, M-1$

$n = 0, 1, 2, \ldots, N-1$