Int. J. Electron. Commun. (AEÜ) 69 (2015) 1254–1264

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Design of quadrature mirror filter bank using polyphase components based on optimal fractional derivative constraints

Kuldeep Baderia[a,*], Anil Kumar[a], Girish Kumar Singh[b]

[a] PDPM-Indian Institute of Information Technology Design and Manufacturing, Jabalpur 482005, India
[b] Indian Institute of Technology Roorkee, Roorkee 247667, India

ARTICLE INFO

Article history:
Received 19 January 2015
Accepted 11 May 2015

Keywords:
Multirate
Polyphase decomposition
Fractional derivative
Lagrange multiplier method
CS and MCS

ABSTRACT

This paper proposes an optimal design of two-channel quadrature mirror filter (QMF) bank using optimized polyphase component enforcing very efficient global swarm optimization techniques cuckoo search (CS) and modified cuckoo search (MCS) based fractional derivative constraints. The objective function is structured in frequency domain, as sum of energy of errors in passband and stopband. This objective function is optimized using a well recognized true least square method called Lagrange multiplier method enforcing CS and MCS based fractional derivative constraints and perfect reconstruction condition of two-channel QMF bank as a constraint. Fractional derivative constraints are optimized by employing CS and MCS algorithms taking peak reconstruction error (PRE) of two-channel QMF bank as an objective function. The proposed method is evaluated by several performance attributes of two-channel QMF bank which promulgate the excellence of proposed method. Comparative results clearly show the superiority of proposed method over recently developed techniques.

1. Introduction

Multirate filter banks have wide area of applications in signal processing such as speech processing [1], image processing [2], biomedical signal processing [3] and several others [4,5]. In signal processing, multirate filter bank plays a very significant role like data compression, reconstruction of signal, detection of harmonics, subband decomposition and recognition of one and two dimensional signal etc. [1–5]. These applications have prompted many researchers and scholars toward optimized multirate filter bank design. Finite impulse response (FIR) [6–11] and infinite impulse response (IIR) [8] are two basic filters, which are employed for constructing multirate filter bank. Due to stability, straight forward and linear phase design, FIR filter is frequently employed for multirate filter design. The most fundamental multirate bank is two-channel quadrature mirror filter (QMF). Two-channel QMF bank is firstly exploited in sub-banding and encoding of speech signal according to its energy content and the process is called as subband coding. Recently, two-channel QMF bank design and its applications are main focus of signal processing researchers because it is fundamental part of various types of filter banks like non-uniform filter banks, tree structure filter banks and other signal processing applications [8,12,13]. The detailed analysis of two-channel QMF bank is given in Section 3.

Literature of two-channel QMF bank shows, recently, various optimization algorithms incorporated in the field of two-channel QMF design [14–24]. In [14], Sahu et al. have designed QMF bank by optimizing filter coefficients employing Levenberg–Marquardt algorithm. Kumar et al. have further improved the QMF design by optimizing filter taps using Quasi-Newton (QN) [15] and Levenberg–Marquardt (LM) methods [16]. Recently, same authors introduced an efficient combination of QN and LM methods for versed design of QMF bank [17]. Nature inspired optimization such as genetic algorithms [18], particle swarm optimization (PSO) and its different variants [19,20], artificial bee colony (ABC) algorithm [20] and adaptive differential evolution (ADE) algorithm [21] are also vouched as an efficient optimization techniques in the field of QMF bank design because of its non-differentiable nature. Most of the nature inspired methods are based on intelligent swarm activity of different species and particles; and due to this reason, it is also termed as swarm based optimization. In [18], signed power-of-two (SPT) coefficients QMF bank has been designed using improved genetic algorithm. Further improvement in QMF design is accomplished by applying PSO [19], modified PSO with ABC [20] and ADE [21] optimization algorithms. Recently, an improved design of QMF bank using fractional derivative constraints has been presented [22] and design has been further improved by using swam

* Corresponding author. Tel.: +91 9424958369.
E-mail addresses: kuldeep_gec2000@yahoo.co.in (K. Baderia), anilkdee@gmail.com (A. Kumar), gksngfee@gmail.com (G.K. Singh).

http://dx.doi.org/10.1016/j.aeue.2015.05.006
1434-8411/

optimization based fractional derivative constraints [23]. Again, an effective design of two-channel QMF bank using polyphase components has been introduced in [24,25]. Multirate filter bank design using polyphase decomposition is very prevalent because of less computational complexity, less data storage and ingenious design. Recently, polyphase decomposition has played a very vital role in designing different types of digital filters and filter banks for various application of signal processing like adaptive multirate filter bank for image compression in [26]. In [27], efficient comb filter has been designed for analog to digital converter employing polyphase decomposition. In [28], polyphase structured multirate filter bank has been designed for image interpolation. In [29], polyphase filtering is used for single carrier modulation.

It is reflected from the literature that polyphase decomposition and swarm based optimization methods are widely used for less complex and highly optimized QMF bank design. Recently, two-channel QMF bank design has been improved using swam optimization and fractional derivative constraints [22,23], and an effective QMF bank has been designed using polyphase decomposition approach [24,25]. But, according to the authors' knowledge, there is no method that has been proposed for optimized design of QMF bank, where polyphase components, fractional derivative constraints and swarm intelligent optimization algorithms are employed simultaneously.

Therefore, in this paper, an improved method for two-channel QMF bank design is proposed, where polyphase components of prototype filter of two-channel QMF bank is optimized using Lagrange multiplier method (a true least square method) by enforcing fractional derivative constraints, which are optimized by two successful swarm-intelligence-based global optimization techniques called CS and MCS algorithms. After a brief introduction over two-channel QMF bank and polyphase decomposition, in Section 2, a brief introduction on fractional derivative constraints is given. Section 3 presents an overview of two-channel QMF bank. In Section 4, problem formulation using polyphase component and CS and MCS based fractional derivative constraints are discussed. In Section 5, a detailed description on the implemented swarm intelligent algorithms (CS and MCS) and the selection process of controlling parameters is given. Section 6 contains the simulation results and discussion on results. Concluding remark is given in Section 7.

2. Overview of fractional derivative

Basically, fractional derivative is a derivative of any dependent function $f(x)$ with real order u [30]. Generally, conventional derivative has order in integer form. In signal processing, fractional derivative is very new concept and recently, it has been employed in various applications such as image processing [31], filter and filter bank design [22,23,32,33] etc. Various definitions of fractional derivative have been proposed by authors and researchers [30]. Due to less complexity and easy formulation, Grunwald–Letnikov definition has been employed in this paper. The mathematical formulation of fractional derivative proposed by Grunwald–Letnikov [30] is

$$D_x^u f(x) = \frac{(d^u f(x))}{(dx^u)} = \lim_{\Delta \to 0} \sum_{k=0}^{\infty} \frac{(-1)^k C_k^u}{\Delta^u} f(x - k\Delta) \quad (1)$$

where, C_k^u is given by

$$C_k^u = \frac{\Gamma(u+1)}{\Gamma(k+1)\Gamma(u-k+1)} = \begin{cases} 1 & k = 0 \\ \dfrac{u(u-1)(u-2), \ldots, (u-k+1)}{1, 2, 3, \ldots, k} & k \geq 1 \end{cases} \quad (2)$$

and $\Gamma(\cdot)$ is the gamma function, $(k-1) \leq u < k$, k is integer.

The fractional derivatives of basic trigonometric functions used in this work are given below:

- **Sine Function**: For $f(x) = A\sin(\alpha x + \beta)$, fractional derivative is:

$$\frac{d^u A\sin(\alpha x + \beta)}{dx^u} = A\alpha^u \sin\left(\alpha x + \beta + \frac{\pi}{2}u\right) \quad (3)$$

- **Cosine Function**: For $f(x) = A\cos(\alpha x + \beta)$, fractional derivative is:

$$\frac{d^u A\cos(\alpha x + \beta)}{dx^u} = A\alpha^u \cos\left(\alpha x + \beta + \frac{\pi}{2}u\right) \quad (4)$$

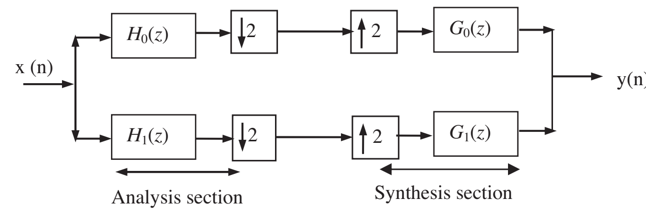

Fig. 1. Two-channel QMF filter bank.

3. Overview of multirate filter bank

Two-channel filter bank is a prime multirate filter bank, which divides the input signal into two subbands, and consists of an analysis and synthesis filter as well as a processing unit between these two banks. The general theory of two-channel QMF banks and their designs were developed by many researchers [14–25]. Consider the generalized block diagram shown in Fig. 1, the reconstructed output $y(n)$ of a QMF bank in z-domain is defined as [11]:

$$Y(z) = 0.5\,[H_0(z)G_0(z) + H_1(z)G_1(z)]\,X(z) + 0.5\,[H_0(-z)G_0(z) + H_1(-z)G_1(z)]\,X(-z) \quad (5)$$

where, $X(z)$ is the input signal in z-domain. In a two-channel filter bank, three types of distortions such as aliasing distortion, amplitude distortion and phase distortion occur due to sub sampling operation and non-ideal frequency and phase response of analysis and synthesis filters. Aliasing distortion can be completely eliminated using [8]:

$$H_1(z) = H_0(-z),\ G_0(z) = H_1(-z) \quad \text{and} \quad G_1(z) = -H_0(-z) \quad (6)$$

Phase distortion in a two-channel filter bank is confiscated by selecting prototype filter $H_0(z)$ as a linear phase finite impulse response (FIR) filter. While, amplitude distortion cannot be vanished completely, it can be minimized using suitable design of two-channel filter bank.

In literature, several efficient methods for designing two-channel QMF banks have been proposed using optimization and non-optimization [14–25]. From the analysis of a two-channel filter bank, zero phase or amplitude response is defined as [8]:

$$\left|T(\omega)\right| = \left\{\left|H_0(\omega)\right|^2 + \left|H_0(\omega - 2\omega_c)\right|^2\right\} \quad (7)$$

where, ω_c is 3 dB cutoff frequency (for two-channel $\omega_c = \pi/2$). For perfect reconstruction, Eq. (7) must be equal to 1, if it is not, then amplitude distortion will take place, and reconstructed output signal will not be the exact replica of original input signal. If the prototype filter of a two-channel QMF bank is assumed to have ideal response in passband (with passband edge frequency ω_p) and stopband (with stopband edge frequency ω_s) as defined by Eq. (8), the reconstruction error exists in transition band. If the amplitude