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Design of frequency response masking FIR filter in the Canonic Signed Digit space using modified Artificial Bee Colony algorithm

Manju Manuel *, Elizabeth Elias

Department of Electronics and Communication Engineering, National Institute of Technology, Calicut, Kerala 673601, India

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ABSTRACT

Frequency response masking (FRM) technique along with the Canonic Signed Digit (CSD) representation is a good alternative for the design of a computationally efficient, sharp transition width, high speed finite impulse response (FIR) filter. This paper proposes two novel approaches for the joint optimization of an FRM FIR digital filter in the CSD space. The first approach uses the recently emerged Artificial Bee Colony (ABC) algorithm and the second approach uses the Differential Evolution (DE) algorithm. In this paper, both the algorithms are modified in such a way that, they are suitable for the solution of the optimization problem posed, in which the search space consists of integers and the objective function is nonlinear. The optimization variables are encoded such that they permit the reduction in computational cost. The salient feature of the above approaches is the reduced computational complexity while obtaining good performance. Simulation results show that the ABC based design technique performs better than that using DE, which in turn outperforms the one using integer coded genetic algorithm (GA). The proposed optimization approaches can be extended to the solution of integer programming problems in other engineering disciplines also.

1. Introduction

If the coefficients of a digital filter are quantized to the Signed Power of Two (SPT) space, then it is possible to replace the multipliers by shift and add operations (Hartley, 1996). Removing the multipliers is equivalent to reducing the circuit complexity and minimizing the power dissipation and chip area. In the SPT space, the CSD is a minimal representation as it represents a given decimal number using minimum number of nonzero SPT terms. In CSD representation, subtractions are also used to carry out multiplications for efficient hardware usage. In this scenario, it is quite advantageous to extend the CSD representation to the digital filter designed using frequency response masking (Yu and Lim, 2002a).

FRM (Lim, 1986) brings forth tremendous savings in the number of multipliers while designing sharp filters with arbitrary bandwidth. The design of the FRM filter having infinite precision coefficients has been well investigated. It involves the design of an interpolated band edge shaping filter and a pair of masking filters. To this end, several publications are available in which the FRM filter coefficients are obtained either by the separate optimization of the various sub-filters or joint optimization of all of them. Linear programming is used for the design of the sub-filters which minimized the weighted error in the pass band and stop band of the overall filter by Lim (1986). Remez algorithm is used by Saramaki and Lim (2003) for the design of FRM FIR filter. The joint optimization of the various sub-filters is done in the following papers. Weighted Least square method is employed by Yu and Lim (2002b) and Lee et al. (2004). Semi-definite programming (Lu and Hinamoto, 2003) and second order cone programming (Lu and Hinamoto, 2008) techniques are used for the design of the continuous coefficient FRM filter. Recently, Neural Network has been employed (Wang and He, 2008) for the design of the FRM filter, in which the coefficients of the sub-filters are optimized simultaneously.

The implementation complexity can be significantly brought down when the FRM filter is represented using CSD. The design of an FRM filter in the discrete space is a complicated process and it calls for the use of efficient nonlinear optimization techniques. The classical gradient based optimization techniques cannot be directly applied to this problem, because here, the search space consists of integers. In this context, meta-heuristic algorithm is a good optimization tool since the proper tuning of the parameters with respect to a particular design problem can bring forth global solution.

Genetic algorithms have been established as a good alternative for the optimization of multimodal, multidimensional problem.

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* Corresponding author. Tel.: +91 4812401131.
E-mail addresses: manju.manuel@gmail.com (M. Manuel), elizabeth@nitc.ac.in (E. Elias).

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This is a population based evolutionary algorithm where, in each iteration, candidate solutions are generated using genetic operations like reproduction, crossover and mutation. GA is used to design the FRM filter in the SPT space by Yu and Lim (2002a). For GA, there is a chance for entrapment in a local minima in some cases, thereby leading to sub-optimal solutions. This drawback can be avoided by properly modifying GA. A novel GA is reported by Mercier et al. (2007) where a look up table approach is used for the design of FRM filters in the CSD space. Here, the binary equivalent of the index of the look up table is used to obtain the initial seed.

This paper proposes the design of the CSD based discrete FRM filter with reduced computational time using two approaches, one using the recently emerged Artificial Bee Colony algorithm (Karaboga and Basturk, 2008) and another using Differential Evolution algorithm (Storn and Price, 1995). Differential Evolution has been chosen because it requires minimum number of parameters in the initialization process. The ABC algorithm and Differential Evolution algorithm have been modified in this work in such a way that, in the course of optimization, the candidate solutions are integers and efficient exploration and exploitation of the search space is done. A promising aspect of these approaches is that good quality solution is obtained with much reduced computation time. Besides, the proposed joint optimization permits the simultaneous design of the various sub-filters of the FRM filter. Another advantage of the proposed approaches is that, in the course of the optimization, restoration techniques are not needed to bring back the candidate solutions to the legitimate CSD codes, unlike in the design of CSD filters based on genetic algorithm (Ashrafzadeh and Nowrouzian, 1997). For the purpose of comparison, integer coded GA (Manoj and Elizabeth, 2009) is also used to design the discrete FRM filter. It was found that the design based on ABC approach outperforms that based on DE and the one using DE performs better than that using integer coded GA in terms of the frequency domain specifications of the FRM filter. The paper is organized as follows. Section 2 gives an overview of frequency response masking. In Section 3, the CSD representation is briefed. Section 4 gives a brief overview of the ABC algorithm and Differential Evolution algorithm. The statement of the problem is done in Section 5. The design of the continuous coefficient FRM filter is briefed in Section 6. Section 7 illustrates the proposed design of multiplier-less FRM filter using the modified ABC algorithm. Section 8 is concerned with the design of the discrete FRM filter using the modified Differential Evolution algorithm. The results and discussions are presented in Section 9.

2. Overview of frequency response masking

Frequency response masking is a much acclaimed technique for the design of an arbitrary bandwidth, sharp FIR filter with reduced computational complexity (Lim, 1986). Efficient hardware implementation of the filter designed using FRM is possible due to the large number of zero-valued coefficients. It consists of a prototype filter $H_a(z)$, complimentary filter $H_c(z)$, masking filter $H_{ma}(z)$ and a complimentary masking filter $H_{mc}(z)$. The complimentary filter $H_c(z)$ can be realized by subtracting the output of the low pass filter $H_a(z)$ from the delay block $z^{-0.5(N_a-1)}$, provided, the model filters are FIR in nature. The block diagram of the FRM filter is shown in Fig. 1.

The overall transfer function of the FRM filter can be written as follows:

$$H(z) = H_a(z^M)H_{ma}(z) + (z^{-0.5(N_a-1)M} - H_a(z^M))H_{mc}(z) \tag{1}$$

The prototype filter, also called the band edge shaping filter, is interpolated by a factor M and therefore its transition width is reduced by a factor of M. The masking filters are used to retain the necessary spectrum repetitions for the formation of any arbitrary bandwidth filter under consideration.

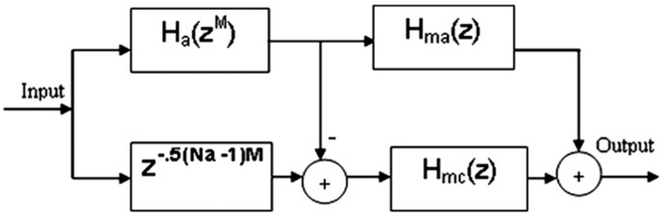

Fig. 1. Frequency response masking filter.

3. Canonic Signed Digit representation

Multiplier-less techniques are used to avoid the need of establishing an expensive general purpose multiplier on, say, the FPGA. Among the multiplier-less techniques, Canonic Signed Digit representation is an encoding where a binary number contains the fewest number of nonzero bits (Hartley, 1996). Therefore, the number of partial product additions in a hardware multiplier can be brought down, when the filter coefficients are encoded in the CSD format. The features are as follows.

(a) It is a minimal representation.
(b) It has a unique SPT representation for a given decimal input.
(c) It is a ternary system.
(d) No two consecutive bits are nonzero.
(e) An N bit CSD number cannot have more than $(N+1)/2$ nonzero bits, often fewer.

Any infinite precision multiplier coefficient 'd' can be represented using the CSD format as follows:

$$d = \sum_{i=1}^{L} a_i 2^{R-i} \tag{2}$$

where 'L' is the wordlength of the CSD number and integer 'R' represents a radix point in the range $0 < R < L$. Besides

$$a_i a_{i-1} = 0 \tag{3}$$

$$a_i \in \{-1, 0, 1\} \tag{4}$$

4. Overview of the Artificial Bee Colony algorithm and Differential Evolution algorithm

This section gives an overview of the Artificial Bee Colony algorithm and Differential Evolution algorithm.

4.1. Artificial Bee Colony (ABC) algorithm

Introduced by Karaboga and Basturk (2008), the Artificial Bee Colony algorithm has been proven to be an efficient tool in finding out the potential solutions for a multidimensional, multimodal optimization problem. The artificial colony of the honey bees comprises the following types of bees: employed bees, onlookers and scouts. A bee waiting on the dance area for making the decision to choose a food source is called an onlooker and a bee going to the food source visited by itself previously is called an employed bee. The scout bee is responsible for carrying out random search. The food source represents a possible solution to the problem. The number of food sources is the same as the number of employed bees. The algorithm starts by deputing an