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Research Article

Metaheuristic FIR Filter Design with Multi-Objective Atomic Orbital Search Algorithm

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Abstract

In this study, atomic orbital search, one of the newly proposed metaheuristic algorithms, is used to design high-performance and low-order FIR filters in MATLAB. The performance parameters of the designed filter were compared with the given literature. The objective function of filter design includes minimization of pass band ripples and stopband ripples, stop band edge frequency attenuation, square sum of the errors between the estimated frequency response and the ideal filter response. The comparison result shows the proposed method performs better than most algorithms and can be used in practical applications.

Keywords: Metaheuristic, Optimization, FIR Filter Design, Multi Objective.

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1. Introduction

Simple building blocks designed on Digital Signal Processing (DSP) systems are called digital filters (Litwin, 2000). There are two main types of filters: infinite impulse response (IIR) filters and finite impulse response (FIR) filters. FIR filters are linear time-invariant (LTI) systems consisting of weighted sums of each input sequence. These systems, which are always stationary, have a linear phase response and due to these advantages, they have wide usage areas. FIR filters can be applied to signals for noise reduction, desired frequency enhancement or suppression (Oppenheim, 1999). In this study, an optimization-based filter design was carried out and a filter with the desired properties was created by optimizing the specified parameters of the filter.

There are two approaches to FIR filter design. The first of these are classical methods, while the other is optimization-based methods. In classical methods, windowing, frequency sampling, and weighted least squares FIR filter design can be done. However, in these methods, parameters such as pass and stop band fluctuations, pass band width, pass and stop band cutoff frequency cannot be controlled as desired. In optimization-based designs, which is another approach, these parameters are defined as an error function and it is aimed to minimize this error function.

There are various optimization-based applications for FIR filter design (Parks & Burrus, 1987; Proakis, 2001). For optimization-based filter design in the literature; There are studies using Genetic Algorithm (GA) (Karaboga & Cetinkaya, 2004; Kaya & İnce, 2011; Najjarzadeh & Ayatollahi, 2008; Zhang et al., 2003), Particle Swarm Optimization Algorithm PSO (Chen & Luk, 2010; Gupta & Mehra, 2011; Najjarzadeh & Ayatollahi, 2008), Differential Evolution Algorithm (DE) (Karaboga, 2005; Karaboga & Cetinkaya, 2006; Reddy & Sahoo, 2015)Artificial Bee Colony Algorithm (ABC) (Bose et al., 2014; Karaboga, 2009; Karaboğa & Çetinkaya, 2011; Latifoğlu, 2013), Harmony Search Algorithm (HA) (Manuel & Elias, 2012; Saha et al., 2014), Squirrel Search Algorithm (SSA) (Karakaş & Latifoğlu, 2020), Black Widow Optimization (BWO) (Karakas & Latifoglu, 2021).

2. Material and Method

In this study, a low-order and low-pass FIR filter is designed using Atomic Orbit Search (AOS) algorithm. In this algorithm, the basic principles of quantum mechanics, quantum-based atomic model methodology and the general configuration of electrons around the nucleus are used. The basic idea of the AOS optimization algorithm; The fundamental principles of electron density configuration and absorption or emission of energy by atoms are exploited in quantum-based atomic theory (Azizi, 2021a).

An ideal FIR filter can be expressed using difference in the following;

$$h[n] = \sum_{k=0}^{M} b_k \delta[n-k]$$

The bk coefficients given in the equation are the coefficients of the FIR filter and are the values that are tried to be optimized in this study.

In this study, the atomic orbital search (AOS) algorithm optimizes the bk coefficients by using the designed objective function. The main concept of AOS is based on some principles of quantum mechanics and the quantum-based atomic model in which the general configuration of electrons around the nucleus is in perspective (Azizi, 2021b). In this study, optimization-based FIR filter design was carried out for the first time in the literature by using AOS, one of the new generation metaheuristic algorithms.

In this study, filters of different orders with a normalized passband cut-off frequency (wp) of 0.4 pi and a normalized stopband cut-off frequency (ws) of 0.6 pi were optimized. An ideal filter with these properties is shown below.

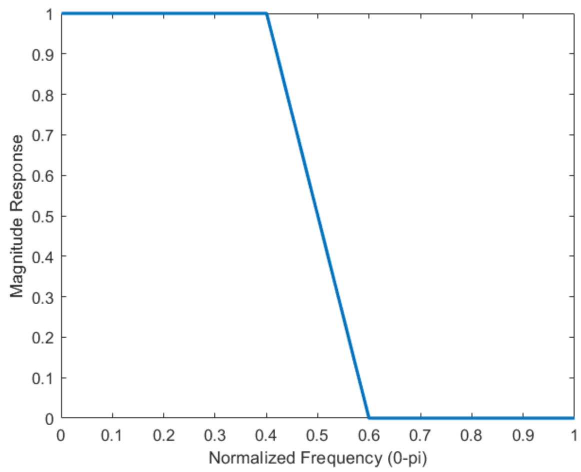

Figure 1 Ideal Filter Response

The error function used for the filter to be designed is the sum of the parameters given below and it is desired to be minimized for this study.

- Square sum of the difference between estimated and desired filter response. (dif)
- Passband Ripple. (pr)

$$pr = \max\left\{Peaks\left(H(e^{jw})\right)\right\} w \leq w_p$$

- Stopband Ripple. (sr)

$$sr = \max\left\{Peaks\left(-H(e^{jw})\right)\right\} w \geq w_s$$

- Stop Band Edge Frequency Attenuation Point. (est)

$$est = (H(e^{jw})\ w = w_s)$$

For an ideal filter, all parameters defined above should be zero. These parameters are determined as the error vector for AOS and the error vector and the error function are defined as follows.

$$Error(X) = [dif\ pr\ sr\ est]$$

$$Total\ Error = \sum_{i=1}^{4} X_i$$

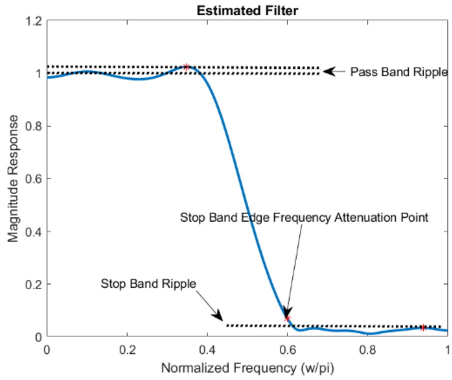

Figure 2 Ideal Filter Parameters

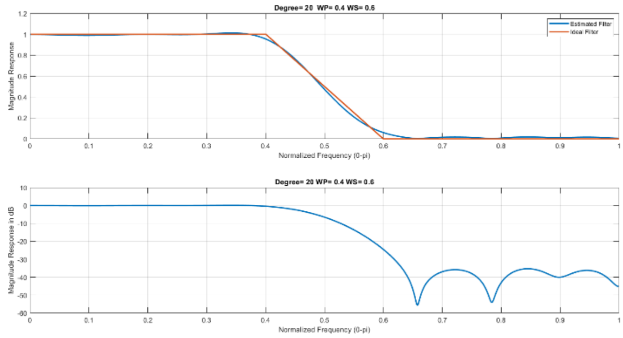

Figure 3 Estimated Filter Response

3. Results

In this study, we design a low pass order 20 FIR filter with a normalized passband frequency of 0.4 and a normalized stopband frequency is 0.45. In the MATLAB environment, we obtained 21 optimised coefficients given in Table 1 and the magnitude response is shown in Figure 3.

Table 1 Coefficients

	Coefficients
h(1)	-0.0088773005746 7292
h(2)	0.0148699194678424
h(3)	0.0114311396074544
h(4)	-0.0327482003827030
h(5)	-0.0348956729741525
h(6)	0.0444437585383665
h(7)	0.00844305416319114
h(8)	-0.261401649031592
h(9)	-0.487546021523425
h(10)	-0.359445145781328
h(11)	-0.0229371317224002
h(12)	0.129062732099396
h(13)	0.0494634041115472
h(14)	-0.0361683457332935
h(15)	-0.0256565923200639
h(16)	0.0129065617697857
h(17)	0.0122948504198526
h(18)	-0.00574123309591572
h(19)	-0.00520042186907001
h(20)	-0.00210494988525669

Table 2 Comparison

Algorithm	**Stopband Ripple**
DE (Karaboga & Cetinkaya, 2006)	0,0960
GA (Karaboga & Cetinkaya, 2006)	0,0532
ABC (Kumar et al., 2017)	0,1138
PSO (Sarangi et al., 2020)	0,0778
Proposed Method	**0.0172**

4. Conclusions

In this study, an order 20 low pass FIR filter by using Atomic Orbital Search Algorithm is designed. It is seen it made improvements from other methods and this method can be used in practical filter design.

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