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Research Article

Design of Digital Low Pass FIR Filter Using Hybrid Particle Swarm – Grey Wolf Optimization Algorithm

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Abstract

In this study, digital low-pass Finite Pulse Response (FIR) filter is designed using Hybrid Particle Swarm – Grey Wolf Optimization Algorithm (HPSGWO). The purpose of digital FIR filter design with HPSGWO is to optimized filter coefficients that are closest to the characteristics of the ideal filter. The obtained results are compared with PSO, and GWO algorithms which were previously used for FIR filters design in the literature. According to the obtained results, HPSGWO has better filter response and less stop band ripple than other methods.

Keywords: finite impulse response (FIR), particle swarm optimization (PSO), grey wolf optimizer(GWO), hybrid particle swarm – grey wolf optimization (HPSGWO).

Hibrit Parçacık Sürü Gri Kurt Optimizasyon Algoritması Kullanılarak Dijital Alçak Geçiren FIR Filtresinin Tasarımı

Öz

Bu çalışmada, Hibrit Parçacık Sürü – Gri Kurt Optimizasyon Algoritması (HPSGKO) kullanılarak sayısal alçak geçiren sonlu dürtü yanıtlı filtre (FIR) tasarlanmıştır. HPSGKO ile dijital FIR filtre tasarımının amacı, ideal filtrenin özelliklerine en yakın filtre katsayılarını optimize etmektir. Elde edilen sonuçlar, literatürde daha önce FIR filtre tasarımı için kullanılan PSO ve GKO ile karşılaştırılmıştır. Elde edilen sonuçlara göre, HPSGKO diğer yöntemlere göre daha iyi filtre yanıtına ve daha az maksimum durdurma bandı dalgalanmasına sahiptir.

Anahtar Kelimeler: sonlu dürtü yanıtı (FIR), parçacık sürüsü optimizasyonu (PSO), gri kurt optimizasyonu (GKO), hibrit parçacık sürüsü – gri kurt optimizasyonu (HPSGKO)..

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1. Introduction

Filtering is widely used in signal processing to convert the frequency spectrum of the input signal to the desired characteristic. Digital filters have an important role in the communication systems, image processing, and processing of biomedical signals [1]. Two types of digital filter design are possible, Infinite Pulse Response (IIR) and Finite Pulse Response (FIR) [1]. Although IIR filters have less memory and less filter coefficient than FIR filters, FIR filters are linear and stable [2]. The characteristic of a designed digital filter is expected to be closest to the ideal filter characteristic. That is, it is expected to converge rapidly to the cutoff frequency, with the minimal ripple in the pass-band and the maximum stop-band attenuation. Stop-band attenuation gives information about the maximum ripple amount in decibel in the stop-band region and it is infinite for the ideal filter. Windowing types such as rectangular, Kaiser, Hamming, Hanning, Blackman are used as classical methods in filter design [1], [3]. Although the rectangular windowing method converges to the cutoff frequency faster than other classical methods, the ripples in the pass and stop bands are higher. In windowing methods such as Kaiser, Hamming, Hanning, and Blackman, the ripple in the pass and stop bands are low, but convergence to the cutoff frequency is too slow. Avci design exponential -hamming FIR filter to increase stop-band attenuation [4]. Although this filter has more stop-band attenuation than the hamming, kaiser, and hamming filter, has less stop-band attenuation than the Equiripple FIR filter.

In recent years, FIR filters have been designed with optimization algorithms in order to reduce both the rapid convergence and the ripples in the pass and stop bands in the literature. Gravitational Search Algorithm (GSA) [5], Cat Swarm Optimization (CSO) [6], Particle Swarm Optimization (PSO) [7-8], Genetic Algorithm (GA) [9-10], Cuckoo Search Algorithm (CSA) [11], Artificial Bee Colony (ABC) [12-13], Grey Wolf Optimizer (GWO) [3], and Moth Flame Optimization (MFO) [2] are implemented to design digital FIR filters.

When the magnitude characteristics of the digital FIR filter made with the above-mentioned optimization algorithm are examined, it is seen that there is high ripple in the pass and stop band. In this study, digital low-pass FIR filter design is carried out using the hybrid Particle Swarm – Grey Wolf Optimization Algorithm (HPSGWO) to minimize the ripples in the pass and stop bands. The obtained results are compared with PSO and GWO algorithms, and it is shown that the HPSGWO algorithm has less ripple in the stop band and better suppresses the frequency components above the cutoff frequency.

2. Low Pass FIR Filter Problem Statement

The mathematical representation of the FIR filter is shown in equation 1.

$$H(z) = \sum_{n=0}^{N-1} h[n] z^{-n} \tag{1}$$

In Equation 1, *N-1* represents the order of the filter, and h[n] represents the impulse response of *N* filter coefficients.

In the literature, the filter is classified into four types according to its length and property of symmetry. In this study, the filter design is carried out by considering the odd length and even symmetric defined as Type 1. With the advantage of the symmetry feature, *1+(N-1)/2* filter coefficients of filter are estimated, then all the filter coefficients of h[n] are obtained. The mathematical expression of magnitude response of the filter for the Type 1 is shown in Equation 2.

$$H_d(\omega) = h[\frac{N-1}{2}] + 2\sum_{n=0}^{(\frac{N-1}{2})-1} h[n]\cos((\frac{N-1}{2} - n)\omega) \quad (2)$$

The magnitude response of the ideal low-pass FIR filter is shown in Equation 3.

$$H_i(w) = \begin{cases} 1, & 0 \le \omega \le \omega_c \\ 0, & otherwise \end{cases} \quad (3)$$

where, ω_c represents the cut off frequency.

In this study, the objective function defined in the literature as the absolute magnitude response error between the ideal and the designed filter shown in Equation 4 is minimized using the HPSGWO algorithm. In the equation 4, δ_p and δ_s are the passband and stopband ripples, respectively.

$$e(\omega) = \sum_{\omega=0}^{\omega_c} \left| \left| H_d(\omega) \right| - H_i(\omega) \right| - \delta_p \Big| + \sum_{\omega_c+1}^{\pi} \left| \left| H_d(\omega) \right| - H_i(\omega) \right| - \delta_s \Big| \quad (4)$$

3. Hybrid PSO–GWO (HPSGWO)

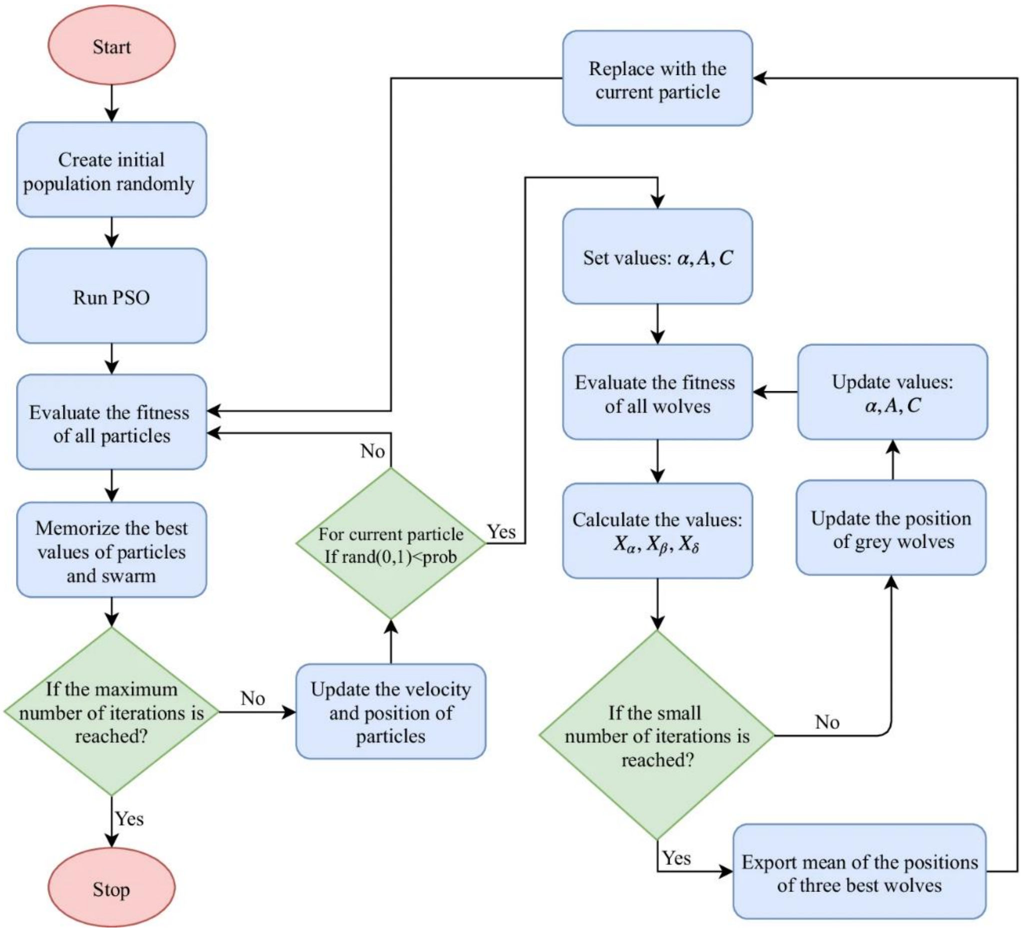
PSO and GWO are popular meta-heuristic algorithms preferred for many problems in the literature. Şenel developed the hybrid PSGWO algorithm by combining the GWO algorithm with the PSO algorithm in order to reduce the probability of the PSO algorithm catching a local minimum [14]. Thus, instead of randomly assigning the particles in the solution space in PSO, it is aimed to obtain more optimum results by directing them to the positions determined by the GWO algorithm. The flow diagram and the pseudocode of the HPSGWO algorithm is shown in Figure 1 [14].

In Figure 1, X_α, X_β and X_δ represent the best three wolves in each iteration. In addition, *A* and *C* in Figure 1 are the coefficient vectors of the GWO, and their mathematical expressions are shown in Equations 5 and 6.

$$A = a(2r_1 - 1) \quad (5)$$

$$C = 2r_2 \quad (6)$$

where a is the coefficient that decreases linearly from 2 to 0 as the number of iterations increases, and r_1 and r_2 are random numbers that change between 0 and 1.

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Pseudocode of HPSGWO Algorithm
Initialize particles
  for i = 1 :1: 1000
      for j = 1 :1:200 do
         Run PSO
         Update the velocity and the position of current particle
       if rand(0, 1) < prob
          Set a, A,C parameters
          for k = 1 :1: 10 do
              for m = 1 :1:10 do
                  Run GWO
                   Update the  α, β and δ  wolves and a, A,C parameters
              end for
          end for
          position of current particle = mean of the positions of three best wolves
       end if
    end for
  end for
```

Figure 1. Flow chart of HPSGWO algorithm [14].

4. Simulation Results

The simulation results are performed with the help of MATLAB based on the values given in Table 1 which are frequently used in the literature. The order of the low-pass FIR filter is chosen as 20 and because of the symmetry, 11 coefficients are estimated by the HPSGWO algorithm. In order to obtain the best filter coefficients, the algorithm is run 50 times and the obtained best filter coefficients are shown in Table 2.

Table 1. FIR filter design parameters

Parameters	Value
Particular Size	200
Iteration Number	1000
Filter Order	20
Number of Frequency Samples	128
Pass-band Ripples (δ_p)	0.01
Stop-band Ripples (δ_s)	0.01
w_c	0.5π

Table 2. HPSOGWO low pass FIR filter coefficients of order 20

h(N)	HPSGWO
h(1)=h(21)	0.0024
h(2)=h(20)	0.0176
h(3)=h(19)	-0.0009
h(4)=h(18)	-0.0324
h(5)=h(17)	0.0033
h(6)=h(16)	0.0523
h(7)=h(15)	-0.0032
h(8)=h(14)	-0.1008
h(9)=h(13)	0.0040
h(10)=h(12)	0.3152
h(11)	0.4971

Figure 2 shows the magnitude responses of low-pass FIR filters performed with HPSWGO, PSO and GWO algorithms. As seen in Figure 2, filter response of HPSGWO algorithm is better than PSO and GWO algorithms. Also, the FIR filter obtained with the HPSGWO algorithm has less ripple in the stopband. Table 3 shows the stop-band attenuation of the filters obtained by HPSGWO, PSO and GWO algorithms. When Table 3 is examined, it is clearly seen that the designed filter obtained with the HPSGWO algorithm has a higher stop-band attenuation. Thus, the characteristic of the low-pass FIR filter designed with the HPSGWO algorithm is closer to the characteristic of the ideal low-pass filter.

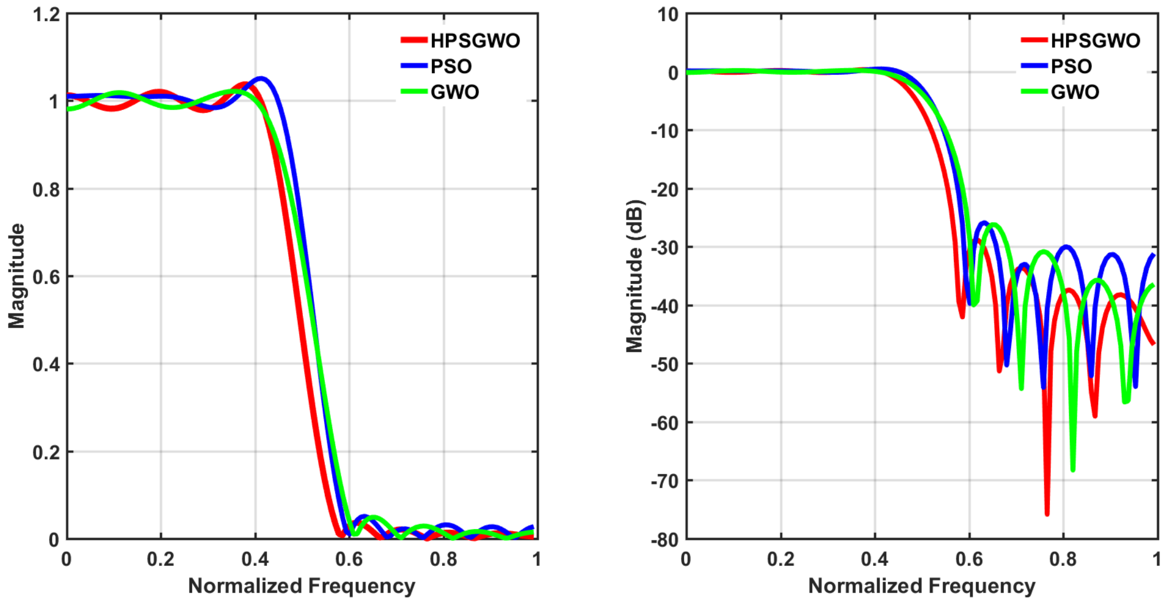

Figure 2. Magnitude response of low pass FIR filter of order 20

Table 3. Stop-band attenuation of HPSGWO, GWO and PSO algorithms

Algorithm	HPSGWO	GWO	PSO
Stop-Band Attenuation	28.8	26.2	25.8

5. Conclusion

The purpose of the digital FIR filter design is to obtain the filter coefficients of the filter response that are closest to the ideal filter response. In this study, a digital low-pass filter is designed with the HPSGWO algorithm, and it is shown that the filter response has less oscillation and is closer to the ideal real filter response than the filters realized with PSO and GWO algorithms. As a further study, it is planned to use the FIR filter designed with the HPSGWO algorithm in real system applications.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

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