Optimal Design of High Pass FIR Digital Filter Using Predator Prey Optimization Technique

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Abstract
This paper presents designing of optimal digital FIR high-pass filter using predator prey optimization technique (PPO). Predator prey optimization is undertaken as a global as well as local search technique. The PPO algorithm has been implemented for the design of high pass FIR digital filter by optimizing its control parameters. The magnitude and phase response have been observed using MATLAB. The achieved results have been compared with the results of other research.

Keywords: *high pass FIR digital filter, PPO technique, ripples magnitude, optimization methods.*

I. INTRODUCTION
Signal processing is a technology with the aim of encompasses the fundamental theory, algorithms, applications and implementations of processing information contained in various different figurative, physical or conceptual formats generally nominated as signals [6]. Digital signal processing (DSP) is the mathematical handling of data and signals in discrete time signals. Because of its good performance, more flexibility, lesser equipment production cost, better time response and environment stability, it turns out to be a popular application in electronic engineering. The main component in DSP that help in performing all the basic function like filtering, adding and separating signals is the digital filter[10].

A frequency selective circuit that allows a certain band of frequency to pass while attenuating the other frequencies is called a filter. A filter is a device that removes harmful constituents in the form of noise from a signal. Filters are classified into two categories: analog filters and digital filters. Analog filter: Analog filters are the device that operates on continuous-time signals.

These filters use passive components such as resistor, capacitors and op-amplifier to realize its effectiveness in the field of noise reduction, video signal enhancement and graphic equalizer. Digital filters: In signal processing, a digital filter is a system that performs mathematical operations on a sampled, discrete-time signal to achieve the desired features with the help of specially designed digital signal processor chip. It is characterized by the representation of discrete time, discrete frequency or other discrete domain signals by a sequence of numbers or symbols and the processing of these signals. To perform the processing digitally, there is a need for an interface between the digital processor and the analog signal. A digital signal processor is an integrated circuit designed for high-speed data manipulations and is used in audio, communications, image manipulation and other data acquisition and data control applications. A filter is frequency discriminating circuit that allows the certain range of frequencies to pass through attenuating other. Filters are used in applications like radar, noise reduction, audio processing, video processing etc. Digital filters are of two types: Finite impulse response (FIR) and Infinite impulse response (IIR) filter. A finite impulse response (FIR) is a type of digital filter whose impulse response is of finite duration. Whereas an IIR filter has infinite impulse response exists for zero to infinity. FIR filter has a number of advantages: High stability, linear phase response, low quantization noise, simple implementation [8]. There are many traditional techniques used for the design of digital FIR filters, like window based methods, frequency sampling method and least mean square error etc. There are variety of windows (Blackman, Hamming, Rectangular, Kaiser etc.), which limites the infinite impulse response of ideal filter into finite window to design actual response[1-8]. But various window methods do not allow sufficient and precise control of frequency response in different frequency band and transition width etc. Parks and mcClellan[1] developed Chebyshev approximation method, that is better than other traditional techniques, but it too has limitation of computational complexity and high pass band ripples.

Generic algorithm gives better results than window method and Parks and McClellan optimization technique [9]. Steepest method of optimization can approximate any kind of frequency response for linear phase FIR filter but the transition width is to be compromised which is not acceptable. The other classical gradient based optimization methods are not suitable for FIR filter optimization[7]. The Gradient optimization method is not appropraite for the discontinuous function and for the function in which derivatives do not exist. This is the main disadvantage of gradient method, only the value of objective function are used to realize the search strategy for locating the least point and these methods doesn't use any derivative of the objective function. So, the direct search method is appropraite only for finding the local solution[7].

Evolutionary optimization techniques such as Genetic Algorithm, Differential Evolution have been implemented for the design of optimal digital filters[3].

This paper demonstrates the design of digital filter using PPO. DE algorithm tries to find the best coefficients that closely match the desired frequency response. The achieved results have been compared with the results obtained by [12].

This paper has been organized in five different sections as follows. The design formulation of FIR digital filter is given in Section II. Section III discusses the overview of predator prey optimization algorithm design for FIR digital filter. Section IV consists of simulation results obtained from high pass FIR digital filter. Conclusion have been discussed in Section V.

II. DESIGN FORMULATION OF DIGITAL FILTER

The FIR filter is a digital filter with finite impulse response. FIR filter are also known as non-recursive digital filters. FIR do not have feedback from output back to input. FIR filters are implemented using a transversal filter. The transversal filter is also known as a tapped delay line filter. It consists of three basic elements: unit delay element, multiplier and adder.

The difference equation of FIR filter is as given below:

$$y(n) = \sum_{K=0}^{M-1} a_k x(n-k) \qquad (1)$$

where y(n) is output sequence, x(n) is input sequence, a_k is coefficient, M is the order of filter.

The transfer function of FIR filter is given as:

$$H(z) = \sum_{K=0}^{M-1} a_k Z^{-k} \qquad (2)$$

The unit sample response of FIR system is identical to the cofficient (a_k), that is

$$h(n) = \begin{cases} a_n, & 0 \le n \le M-1 \\ 0, & \text{otherwise} \end{cases} \qquad (3)$$

The output sequence can also be expressed as convolution of unit sample response h(n) of the system with its input signal.

$$y(n) = \sum_{K=0}^{M-K} h(n)x(n-k) \qquad (4)$$

FIR filter have symmetric and antisymmetric properties, which are related to their h(n) under symmetric conditions as described below by equation:

h(n) = h(N-1-n) for Symmetric (5)

h(n) =-h(N-1-n) for Asymmetric (6)

For such a system the number of multiplication is reduced from N to N/2 for N even and to (N-1)/2 for odd.

The FIR filter is designed by optimizing the coefficients in such a way that the approximation error function in L_p-norm for magnitude is to be kept minimal. The magnitude response is specified at K equally spaced discrete frequency points in pass-band and stop band.

$$e_1(x) = \sum_{i=0}^{K} \left| H_d(w_i) - |H(w_i, x)| \right| \qquad (7)$$

$$e_2(x) = \sum_{i=0}^{K} \left(\left| H_d(w_i) - |H(w_i, x)| \right| \right)^2 \qquad (8)$$

where e_1(x) is absolute error l_1-norm for magnitude response and e_2(x) is squared error l_2-norm of magnitude response.

Desired magnitude response of FIR filter is given as:

$$H_d(w_i) = \begin{cases} 1 \; for \; w_i \in passband \\ 0 \; for \; w_i \in stopband \end{cases} \qquad (9)$$

The ripple magnitudes of pass-band and stop-band are to be minimized which are given by δ_1(x) and δ_2(x) in Equ. 10 and Equ. 11 respectively.

$$\delta_1(x) = \max |H(w_i, x)| - \min |H(w_i, x)| \qquad (10)$$

$$\delta_2(x) = \max |H(w_i, x)| \qquad (11)$$

Three objective functions for optimization are:

Minimize $f_1(x) = e_1(x)$ (12)

Minimize $f_2(x) = e_2(x)$ (13)

Minimize $f_3(x) = \delta_p(x)$ (14)

The multi-objective function is converted to single objective function:

Minimize f(x) = $w_1 f_1(x) + w_2 f_2(x) + w_3 f_3 + w_4 f_4$ (15)

w_1, w_2, w_3 and w_4 are weights.

III. PREDATOR PREY OPTIMIZATION TECHNIQUE

In the conventional PSO algorithm, the swarm would come together at a time and then it must be difficult for them to escape from the accumulator point. After that, the algorithm would lose its global search ability. For overcoming this deficiency of PSO, a predator-prey model has been developed by Silva[4]. The motivation has mainly introduced diversity in the swarm position at any moment during the run of the algorithm, which does not depend on the level of convergence already achieved. Higashitani[5] have developed the predator prey optimization (PPO) method and applied on several benchmark problems and has compared with PSO method. It has concluded that PPO performed significantly better than the standard PSO while implanted on benchmark multimodal functions.

The predator velocity representing decision variable, updates for $(t+1)^{th}$ iteration are given below:

$$V_{pi}^{t+1} = C_4\,(G\,Pbest_1^t + P_{pi}^t)\ (i=1, 2....S) \qquad (16)$$

The predator position representing decision variable, updates for $(t+1)^{th}$ iteration are given below:

$$X_{pi}^{t+1} = X_{pi}^t + V_{pi}^{t+1}\ (i=1, 2..........S) \qquad (17)$$

where GP $best_i^t$ is global best prey position of i^{th} variable, C_4 is random number lies between 0 & upper limits.

The prey velocity representing decision variable, updates for $(t+1)^{th}$ iteration are given by:

$$v_{ik}^{t+1} = \begin{cases} wv_{ik}^t + Ac_1R_1(Xbest_{ik}^t - X_{ik}^t) + A\,c_2R_2(Gxbest_{ik}^t + X_{ik}^t) & ; p_f \le p_f^{max} \\ wv_{ik}^t + Ac_1R_1(Xbest_{ii}^t - X_{ik}^t) + Ac_2R_2(Gxbest_{ik}^t + x_{ik}^t) + C_2a(e^{-ixt}) & ; p_f > p_f^{max} \end{cases}$$

(i=1,2.......S;K=1,2.....N_p) (18)

The prey velocity representing decision variable, updates for $(t+1)^{th}$ iteration are given by:

$$X_{ik}^{t+1} = x_{ik}^t + C_{ik}v_{ik}^{t+1} \quad (i = 1,2,\ldots,S; K1,2,\ldots.N_p)$$

(19)

where Ac_1 and Ac_2 is acceleration constant, R_1 and R_2 is uniform random numbers having value between 0 and 1, W is inertia weight.

Algorithm:

1. Initialize the parameters such as population size n_p=80, maximum iteration cycles=500, acceleration constants(Ac_1/ Ac_2), maximum and minimum limit of velocity, maximum probability fear (P_f^{max}) etc.
2. Initialize the prey and predator positions and velocities randomly.
3. Apply opposition based strategy.
4. Calculate objective function.
5. Select N_p best preys from total $2N_p$.
6. Calculate the personal best position (pbest) of each prey and then select best value among all pbest values of prey and assign that pbest position as to all preys.
7. Calculate global best position (gbest) among local best position of prey.
8. Update predator velocity and position by using Equ.16 and Equ.17.
9. Generate the probability fear between 0 and1 randomly.
10. IF (probability fear > maximum probability fear) THEN
    Update prey velocity and position with predator affect
    ELSE
    Update prey velocity and position without predator affect
    ENDIF
11. Calculate objective function again for all prey population.
12. Then update local best positions of prey particles by using Equ.18 and Equ.19.
13. Calculate global best position of prey particles based on fitness.
14. Check stopping criteria, if not met, go to step 8.
15. Stop.

Table 1 shows the parameters chosen in order to run evolutionary PPO algorithm.

Table 1: PPO Design Parameters

Parameters	Value
Population size	80
Iteration cycle	500
Ac_1 , Ac_2	2.5,2.5
w_{min}	0.1
w_{min}	0.4
W3,W4	11.0,7.0

Design conditions for the design of FIR high pass filter are given in Table 2. The value for pass-band, stop-band and H(ω, x) are mentioned in the Table.

Table 2: Design condition for high pass FIR digital filter

Filter type	Pass-band	Stop-band	Maximum value of |H(ω,x)|
High-pass	$0.8\pi \le \omega \le \pi$	$0 \le \omega \le 0.7\pi$	1

IV. SIMULATION RESULTS

The design of digital FIR high pass filter has been demonstrated by evaluating filter coefficients using predator prey optimization algorithm. The range of pass-band and stop-band are taken as $0.8\pi \le \omega \le \pi$ and $0 \le \omega \le 0.7\pi$. The PPO algorithm is run for 200 times and 500 iterations have been taken to obtain best results at different orders. Order of filter has been varied from 20 to 34 for the PPO algorithm and objective function is observed.

Table 3 shows objective function value at different filters order 28.

Table 3: Optimized high pass FIR digital filter coefficients of filter order 28

Sr. No.	Coefficients	Value of coefficients
1	20	5.242553

2	22	4.274247
3	24	4.097414
4	26	3.540805
5	28	2.558689
6	30	5.043365
7	32	20.09484
8	34	40.10437

Fig 1 shows the filter order versus objective function. The objective function of DE [12] is minimum at filter order 28 where as objective function of PPO is also minimum at filter order 28 as seen from graph. So, PPO has been compared with DE at filter order 28 in terms objective function, magnitude error 1, magnitude error 2, pass band and stop band performance.

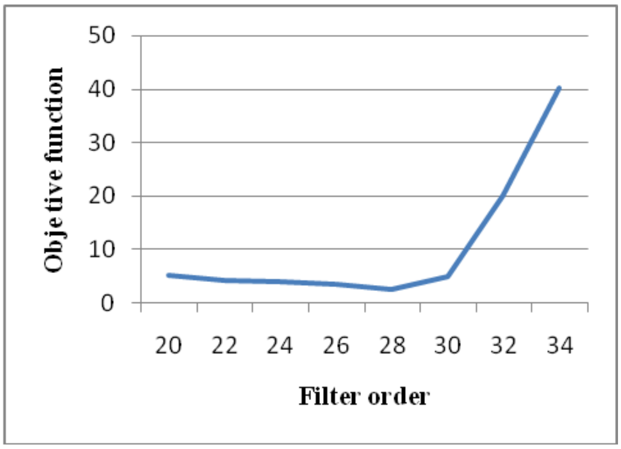

Figure 1: Filter order versus objective function

Table 4, it is observed that PPO has minimum objective function and pass-band ripple magnitude as compared to DE at filter order 28 but stop-band ripple magnitude of PPO is little bit more than DE. It proves the conflicting nature of pass band and stop band ripples.

Table 4: Design results of high pass FIR digital filter at filter order 28

Sr. No.	Algorithm	PPO	DE [12]
1	Objective Function	2.558689	2.669447
2	Magnitude Error 1	1.276657	1.395376
3	Magnitude Error 2	.168388	.170265
4	Pass-band performance	.052967	.061022
5	Stop-band performance	.075850	.49359

Table 5 shows the best optimized filter coefficients obtained for designing high pass FIR digital filter at filter order 28.

Table5: Optimized high pass FIR digital filter coefficients of filter order 28

Sr. No.	Coefficients	Value of coefficients
1	A(0)=A(28)	.006064
2	A(1)=A(27)	-.009426
3	A(2)=A(26)	.004391
4	A(3)=A(25)	.008276
5	A(4)=A(24)	-.020393
6	A(5)=A(23)	.021009
7	A(6)=A(22)	-.004677
8	A(7)=A(21)	-.023078
9	A(8)=A(20)	.045819
10	A(9)=A(19)	-.043594
11	A(10)=A(18)	.003877
12	A(11)=A(17)	.069725
13	A(12)=A(16)	-.156677
14	A(13)=A(15)	.226582
15	A(14)	-.253493

Filter parameters like population size and acceleration constants (Ac_1/Ac_2) have been tuned in order to get more optimum results. So firstly, the population size of PPO algorithm has been varied in the range of 40-140.

Table 6: Population size versus objective function at filter order 28

Sr. No.	Population Size	Objective Function
1	40	2.559141
2	60	2.559805
3	80	2.558689
4	100	2.559047
5	120	2.612418
6	140	2.679822

Above table, it is observed that at population 80 gives the results even better than other population.

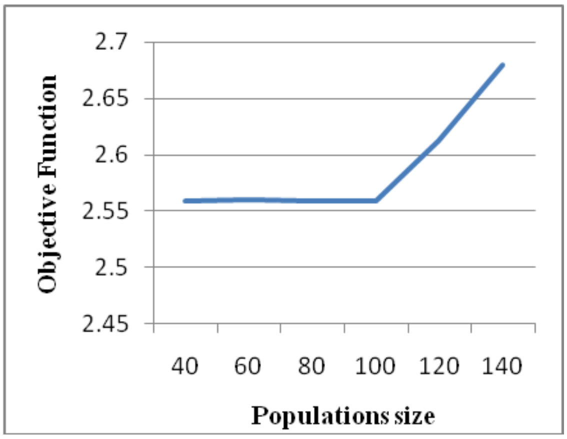

Figure 2: Population size versus objective function at filter order 28

The values of acceleration constants (Ac_1/Ac_2) are varied from 1 to 3.5. The objective function is varying from the value 1 to 2.5 of acceleration constants. There is a gradual increase in the value of objective function for the value of Ac_1, Ac_2 between 2.5 Ac_1, Ac_2 is having value 2.5. So this value of Ac_1, Ac_2 is selected.

Table 7: Acceleration constants versus objective function at filter order 28

Sr. No.	Acceleration Constants (Ac_1/Ac_2)	Objective function
1	1.0	2.562903
2	1.5	2.56016
3	2.0	2.558953
4	2.5	2.558689
5	3.0	2.559617
6	3.5	2.562286

Fig 3, it is observed that the value of acceleration constants that yields the best result is 2.5.

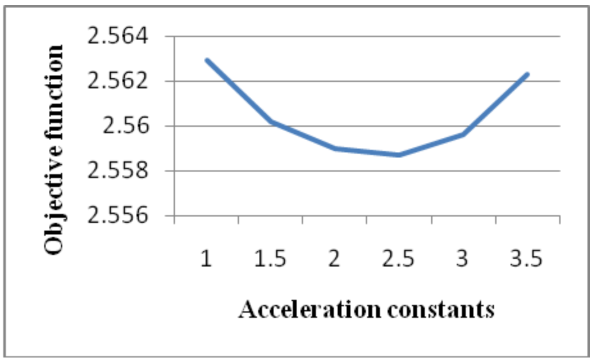

Figure 3: Acceleration constants versus objective function at filter order 28

Fig 4 shows the graph that how the value of objective function varies at different iterations at population size 80.

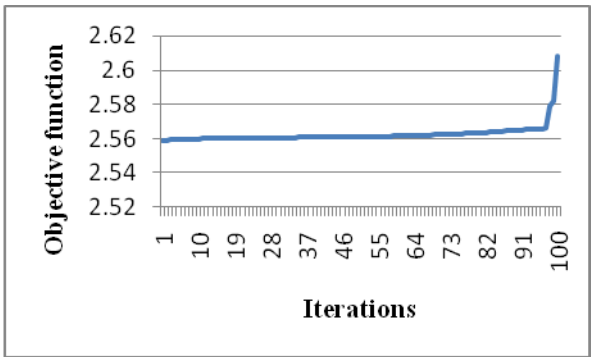

Figure 4: Objective function versus No. of iteration at filter order 28

Fig 5 shows the plot for variation in magnitude response with variation in normalized frequency.

The ideal range of pass-band FIR filter varies from $0.8\pi \leq \omega \leq \pi$ and that of stop band varies from $0 \leq \omega \leq 0.7\pi$ which is shown respectively in fig 1.

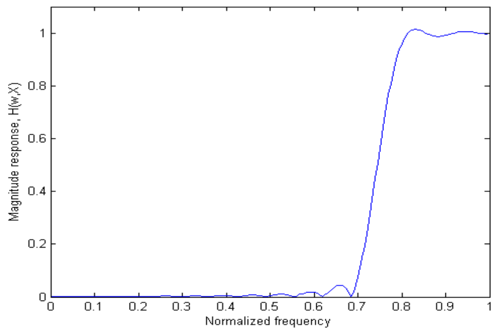

Figure 5: Magnitude response v/s Normalized frequency of high pass FIR digital filter at order 28

Fig 6 shows the graph of variation in magnitude response with variation in normalized frequency in db.

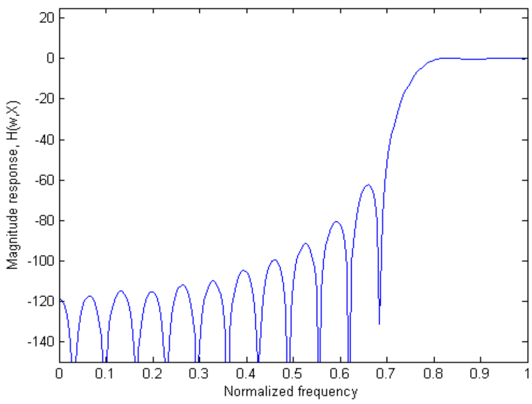

Figure 6: Magnitude response (in db) v/s Normalized frequency of high pass FIR digital filter at order 28

Fig 7 shows the graph of variation in phase response with variation in normalized frequency.

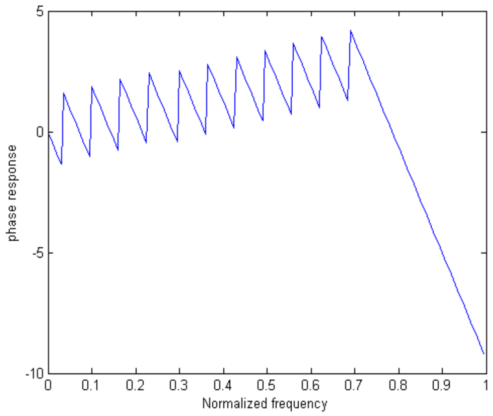

Figure 7: Phase response v/s Normalized frequency of high pass FIR digital filter at order 28

Table 8 standard deviation is very much less than one, which shows the robust nature of designed filter.

Table 8: statistical calculation for high pass FIR digital filter at filter order 28

Sr. No.	Max Objective function	Min objective function	Average value	Standard deviation
1	2.608181	2.558689	2.583435	0.024746

V. CONCLUSION

This paper presents a robust and optimal method to design high pass FIR digital filter by using predator prey optimization (PPO). FIR filter using non linear stochastic global optimization technique based on the PPO approach. Comparision has been carried out between PPO and Differentail Evolution (DE). Firstly, the filter order has been varied from 20 to 34. From simulation results, it is evident that PPO gives better results in terms of objective function, pass band ripple magnitude as compared to DE[12]. Parameters like population size 80, acceleration constants (Ac_1/Ac_2) 2.5, weight 11.0 and 7.0 have been tuned. The achieved value of standard deviation obtained by choosing these parameters is 0.024746 which is less than 1, that authencates that the high pass FIR digital filter is robust and stable. The simulation results clearly reveal that the PPO may be used as a good optimizer for the solution of obtaining the optimal filter coefficients in a practical digital filter design problem in digital signal processing system. The same algorithm can be applied to design band-pass, band-stop and low pass digital FIR filters.

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