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Predator Prey Optimization Technique for the Design of High Pass Digital FIR Filter

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ABSTRACT: ***This paper elaborates the creative procedure for significant and stable design of optimal digital FIR high-pass filter using predator prey optimization technique (PPO). Predator prey optimization is undertaken as a worldwide search technique and tentative search is demoralized as local search technique. Also, Predator prey optimization (PPO) enhances the capability to explore the search space locally as well globally so as to obtain the optimal filter design parameters. The proposed PPO method is a robust technique with inherent parallelism, which can be easily handled with non-differential objective function, unlike other conventional optimization methods. The magnitude and phase response have been observed using MATLAB. The experimental results show that various statistical parameters have been calculated and analyzed for the better designing of FIR high pass digital filter.***

Keywords: FIR high pass digital filter, Optimization methods, PPO technique, ripples magnitude

1. Introduction

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 filters: 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 communication, 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 others. Filters are used in applications like radar, noise reduction, audio processing, video processing etc. Digital filters are 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 [7]. 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 [1-7]. Parks and mcClellan [1] proposed the Chebyshev approximation method that results much better than other traditional techniques, but it too has limitation of computational complexity and high pass band ripples.

GA gives better results than window method and Parks and McClellan optimization technique [8]. 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[6].

Evolutionary optimization technique such as Genetic Algorithm, Differential Evolution are implemented for the design of optimal digital filters [3]. This paper presents the use one of the evolutionary optimization technique called predator prey optimization (PPO) for the design of digital FIR high pass filter. Kennedy and Eberhart [2] have originally introduced partical swarm optimization which is global search technique. In PSO, simulating the social behavior of swarm the birds searching for food. For improving the performance of PSO a new technique Predator Prey Optimization is introduced. It avoids local stagnation and aims to fine tune the solution locally. PPO method works well with random, initialization and satisfies prescribed amplitude. Therefore, the advanced algorithm is a useful technique for design of FIR filters.

This paper has been organized in five different sections as follows. The design formulation of FIR digital filter is given in section 2, section 3 discusses the overview of predator prey optimization algorithm design for FIR digital filter, section 4 consists of simulation results obtained from high pass FIR digital filter, conclusion have been discussed in section 5.

2. Design Formulation of Digital Filter

FIR digital filter is used for Fast fourier Transform (FFT) algorithm to achieve the filtered signal, which are greatly improve the efficiency of operation.The difference equation of FIR filter is as given below:

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

where y(n) is output sequence, x(n) is input sequence, b_k is coefficient, M is the order of filter.
The transfer function of FIR filter is given as:

$$H(z) = \sum_{K=0}^{M-1} b_k z^{-k} \quad (2)$$

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

$$h(n) = \begin{cases} b_n, 0 \le n \le M-1 \\ 0, otherwise \end{cases} \quad (3)$$

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

$$y(n) = \sum_{K=0}^{M-1} h(k)x(n-k) \quad (4)$$

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

$$h(n) = h(N-1-n) \text{ for Symmetric} \quad (5)$$

$$h(n) = h(N-1-n) \text{ for Asymmetric} \quad (6)$$

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 ways 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)-absolute error L_1-norm of magnitude response
e_2(x)-squared error L_2-norm of magnitude response

$$e_1(x) = \sum_{i=0}^{k} (\,|\,H_d(\omega_i) - |H(w_i,x)|\,|\,) \quad (7)$$

$$e_2(x) = \sum_{i-0}^{k} (\,|\,H_d(w_i) - |H(w_i,x)|\,|\,) \quad (8)$$

Ideal magnitude response of FIR filter is given as:

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

The ripple magnitudes of pass-band and stop-band are to be minimized which are given by δ_1(x) and δ_2(x) respectively.
Ripple magnitude are:

$$\delta_1(x) = \max\{\,|\,H(w_i,x)\}-\min\{\,|\,H(w_i,x)\,|\, \quad (10)$$

$$\delta_2(x) = \max\{\,|\,H(w_i,x)\,|\,\} \quad (11)$$

Four objective functions for optimization are:

$$\text{Minimize } f_1(x) = e_1(x) \quad (12)$$

$$\text{Minimize } f_2(x) = e_2(x) \quad (13)$$

$$\text{Minimize } f_3(x) = \delta_p(x) \quad (14)$$

$$\text{Minimize } f_4(x) = \delta_s(x) \quad (15)$$

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

$$\text{Minimize } f(x) = w_1 f_1(x) + w_2 f_2(x) + w_3 f_3 + w_4 f_4 \quad (16)$$

w_1, w_2, w_3 and w_4 are weights.

3. Predator Prey Optimization Technique Employed

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. 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:

$$V_{p_i}^{t+1} = C_4 (G\, Pbest_1^t + P_{p_i}^t) \; (i=1, 2....S) \quad (17)$$

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

$$X_{p_i}^{t+1} = X_{\boldsymbol{p_i}}^{\boldsymbol{t}} + V_{p_i}^{t+1} \; (i=1, 2.........S) \quad (18)$$

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:

$$v_{i_k}^{t+1} = \begin{cases} wv_{ik}^t + C_1R_1(Xbest_{ik}^t - X_{ik}^t) + C_2R_2(Gxbest_{ik}^t + X_{ik}^t)\,;\, p_f \le p_f^{max} \\ wv_{ik}^t + C_1R_1(Xbest_{ii}^t - X_{ik}^t) + C_2R_3(Gxbest_{ik}^t + x_{ik}^t) + C_3a(e^{-ixt})\,;\, p_f > p_f^{max} \end{cases}$$

$$(i=1,2.......S;\; K=1,2.....N_p) \quad (19)$$

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

$$X_{ik}^{t+1} = x_{ik}^t + C_{ik} v_{ik}^{t+1} \; (i = 1,2,\ldots,S; K = 1,2,\ldots N_p) \quad (20)$$

Where C_1 and C_2 is acceleration constant, R_1 and R_2 is uniform random numbers having value between 0 and 1, W is inertia weight.

3.1 Algorithm

1. Input data viz. maximum allowed movements, swarm size, maximum and minimum limit of velocity, maximum probability fear (P_f^{max}) etc.
2. Randomly initialize the prey and predator positions being decision variables.
3. Randomly initialize the prey and predator velocities.
4. Apply opposition based strategy.
5. Compute augmented objective function.
6. Select N_p best preys from total $2N_p$.
7. Assign all prey positions as their local best position.
8. Compute global best position among local best position of prey.
9. Update predator velocity and position.
10. Randomly generate the probability fear within (0,1).
11. 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.

12. Compute augmented objective function for all prey population.
13. Update particles local best position of prey particles.
14. Global best position of prey particles based on fitness.
15. Check stopping criteria, if not met, step 9.
16. Stop.

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

Table 1: PPO Design Parameters

Parameters	*Value*
Population size	100
Iteration cycle	200
C_1, C_2	2.0,2.0
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.

Table 2: Design condition for high pass FIR digital filter

Filter Type	Pass-band	Stop-band	Maximum value of $\|H(\omega, x)\|$
high-pass	$0.8\pi \leq \omega \leq \pi$	$0 \leq \omega \leq 0.7\pi$	1

4. Simulation Results

Predator Prey Optimization (PPO) algorithm applied in order to design the digital FIR high pass filter. The range of pass-band and stop-band are taken as $0.8\pi \leq \omega \leq \pi$ and $0 \leq \omega \leq 0.7\pi$. The PPO algorithm is run for 100 times and 200 iterations have been taken to obtain best results at different orders. Order of filter has been varied from 20 to 40 for the PPO algorithm and objective function is observed.

Table 3 shows objective function value at different filters order.

Table 3: Objective Functions values at different filter orders

Sr. No.	*Filter order*	*Objective function*
1	20	5.242611
2	22	4.273127
3	24	4.105132
4	26	3.540911
5	28	2.558787
6	30	7.187363
7	32	22.67325
8	34	53.61968
9	36	106.3565
10	38	157.1565
11	40	211.1536

Hence the filter order 28 gives the minimum value of objective function. So filter order 28 has been preferred for the design of digital high pass FIR filter. Now variation in filter order with variation in objective function as shown in fig 1.

Figure 1: Filter Order versus Objective Function

Table 4 shows the best optimized coefficients of filter order 28.

Table 4: Optimized high pass FIR digital filter coefficients of filter order 28

Sr. No.	*Coefficients*	*Value of coefficients*
1	A(0)=A(28)	.006099
2	A(1)=A(27)	-.009407
3	A(2)=A(26)	.004398
4	A(3)=A(25)	.008264
5	A(4)=A(24)	-.020342
6	A(5)=A(23)	.021011
7	A(6)=A(22)	-.004699
8	A(7)=A(21)	-.023035
9	A(8)=A(20)	.045768
10	A(9)=A(19)	-.043607
11	A(10)=A(18)	.003946
12	A(11)=A(17)	.069672
13	A(12)=A(16)	-.156615
14	A(13)=A(15)	.226683
15	A(14)	-.253560

Table 5 shows the design results of high pass FIR digital filter.

Table 5: Design results of high pass FIR digital filter at filter order 28

Sr. No.	*Algorithm*	*PSO [11]*	*PPO*
1	Objective Function	2.6694	2.558787
2	Magnitude Error 1	1.396111	1.274461
3	Magnitude Error 2	0.170330	0.167831
4	Pass-band performance	0.060939	0.052777
5	Stop-band performance	0.049359	0.076563

For FIR filter with filter order of 28, the other parameters have been varied to examine the performance of PPO. First of all, population is varied in the range 40-180 and it is observed that at population 100 it gives results even better than other population.

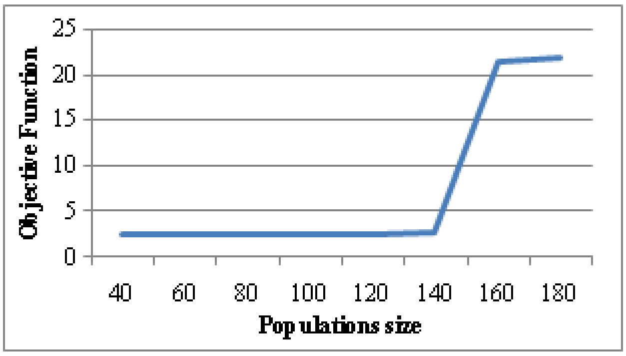

Figure 2: Populations size versus objective function plot of high pass FIR digital filter at order 28

The values of acceleration constants (C_1, C_2) are varied from 1 to 4. The objective function is varying from the values 1 to 2 of acceleration constants. There is a gradual increase in the value of objective function for the values of C_1, C_2 between 2 to 4. The value of objective function is minimum when C_1, C_2 is having value 2. So this value of C_1 and C_2 is selected.

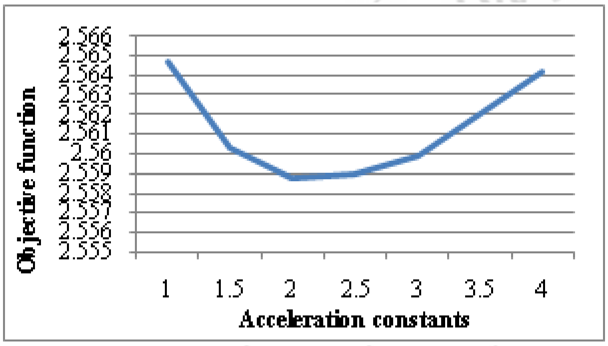

Figure 3: Acceleration constants Objective Function plot of high pass FIR digital filter at filter order 28

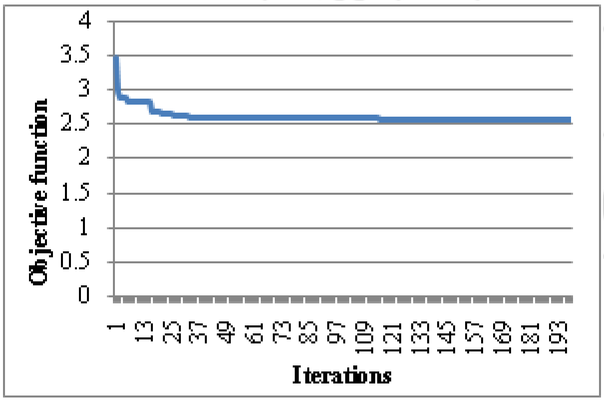

Figure 4: Objective Function v/s No. of iterations at filter order 28

Fig 5 shows the graph of variation in magnitude response with variation in normalized frequency.

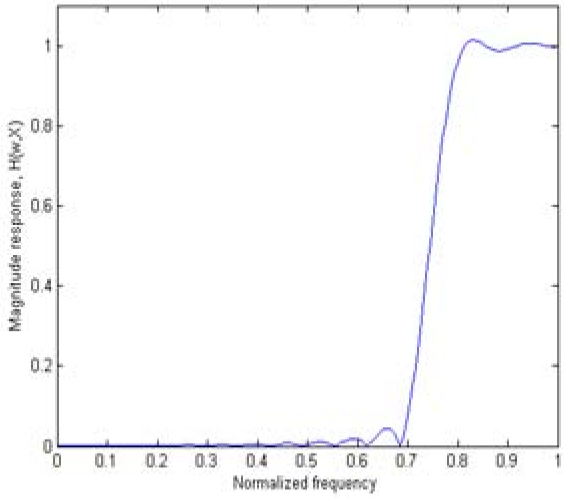

Figure 5: Magnitude response v/s Normalized frequency of high pass FIR digital filter at filter order 28

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

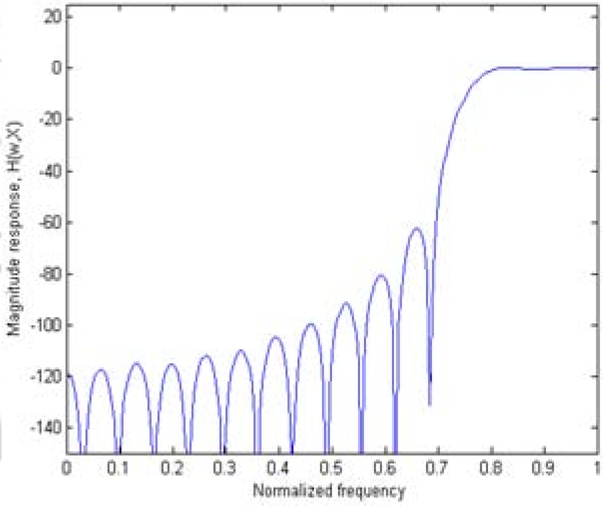

Figure 6: Magnitude response (in db) v/s Normalized frequency of high pass FIR digital filter at filter order 28

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

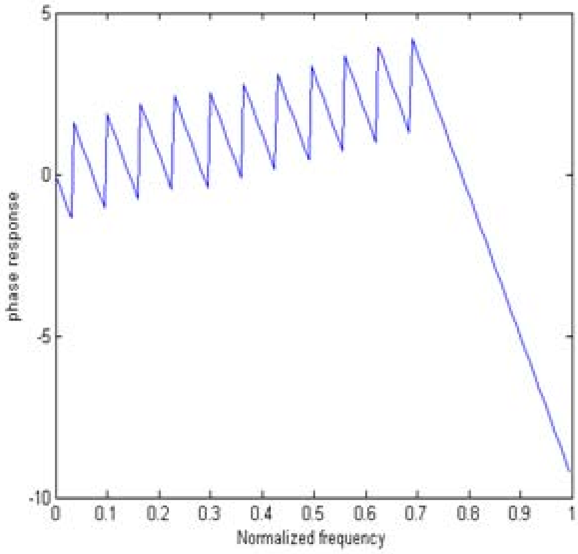

Figure 7: Phase response v/s Normalized frequency of high pass FIR digital filter at filter order 28

Table 6 standard deviation is very much less than one, which shows the robust nature of designed filter.

Table 6: Max, Min and Avg value of objective function along with standard deviation at filter order 28

Sr. No.	Max objective function	Min objective function	Average value	Standard deviation
1	2.614643	2.558787	2.586715	0.027928

5. Conclusion

In this paper, predator prey optimization (PPO) algorithm has been implemented as a promising method for the design of FIR high pass digital filter. The proposed PPO method provides an enormous improvement in the experimental work. The simulation results obtained by proposed PPO are better in magnitude error and ripple magnitude at filter order 28. Parameters like Population size, Acceleration Constants, Weight are used to design the high pass FIR digital filter. Further, the parameters has been varied. When population factor has been varied, it is observed that the designed filter gives better value at population 100. Then, the acceleration constants C_1 and C_2 gave best result at value 2.0 both respectively. Standard deviation obtained is 0.027928 which authenticates robustness of design.

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