Nature inspired optimization technique for the design of band stop FIR digital filter

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***Abstract* - This paper proposes an efficient optimization technique, called Predator Prey Optimization (PPO) for designing an optimal Band Stop FIR digital filter. PPO is a stochastic population based optimization technique that provides optimal filter coefficients and solves local stagnation problem of Particle Swarm Optimization (PSO) technique as the predator produces diversification and results into optimum solutions. PPO is capable of performing local as well as global search. The obtained simulation results show that PPO is superior to PSO. PPO provides robust FIR digital filter and optimizes the filter design by minimizing the value of design parameters that are magnitude errors, pass band ripples and stop band ripples.**

***Key Words* - Digital FIR filter, Predator Prey Optimization, L1-norm error $e_1(x)$, L2-norm error $e_2(x)$, Passband Ripples $\delta_p(x)$, Stop Band Ripples$\delta_s(x)$.**

I. INTRODUCTION

Digital Signal Processing is a rapidly growing field of engineering. Due to advancements made in integrated circuit and digital computer technology, highly sophisticated digital systems came into existence which can perform the complex signal processing tasks with greater degree of accuracy and precision. In addition to this, digital hardware used for signal processing permits the programmable operations. Filter is the most important component of the processing system. Filter is a frequency selective device that allows only certain band of frequencies to pass. It removes unwanted signals (noise), performs equalization and spectral analysis of signal. On the basis of type of signal a filter processes; filters are of two types: Analog and Digital filter. Digital filters have more advantages over analog filters as its working does not get affected by temperature and humidity, digital filters are easy to build and it provides better performance at lower cost. Digital are further classified as Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters depending upon the length of its impulse response [5, 7].

Finite Impulse Response filters have finite impulse response i.e. its response becomes zero at certain point whereas for IIR filters have impulse response that never settle downs to zero. FIR filters have linear phase response and has only poles. On the contrary IIR filters do not provide linear phase response and have both zeros and poles. FIR filters are non-recursive filters i.e. it does not require feedback whereas, IIR filters require feedback i.e. its output depends on past and present input as well as past outputs and hence are known as Recursive filters. FIR filters are more popular because of the convenience and flexibility it offers. FIR filters are symmetrical in nature and are always stable. FIR digital filters have certain disadvantages: FIR filters work on higher filter order, involve more computational complexity, require more memory and work slower than IIR filters. FIR filters are widely used in image processing, signal and speech processing and data transmission [7, 9].

FIR filters can be designed by using different methods. Window method and Frequency Sampling are the most common methods among all. In window method, certain chosen window function truncates the impulse response of the filter. There are different window functions available like Rectangular, Hamming, Hanning, Kaiser, and Blackmann. Selection of these window functions depends on parameters like ripples in pass band and stop band, attenuation in stop band and transition window. Window method is easy to implement and provides fixed attenuation in stop band. But it is not flexible and has not precise specification of pass band and stop band edge frequencies. It does not provide accurate control over parameters of frequency spectrum [4, 11].

Hence, optimization techniques are used for designing an optimal FIR digital filter. Evolutionary optimization techniques work efficiently with multidimensional search spaces. They can be used for the optimization of discontinuous functions. Some of the efficient evolutionary techniques are Artificial Bee Colony, Ant Colony Optimization, Genetic Algorithm, Particle Swarm Optimization, Differential Evolution, Tagauchi method and Predator Prey Optimization. Evolutionary techniques have major disadvantages of slow convergence and may also entrap in local optima solutions [6].

Particle Swarm Optimization (PSO) is a global search technique proposed by Kennedy and Eberhart. It is a population based Nature-Inspired Optimization method. PSO is capable to deal with non differential objective function and larger search space. In PSO, population members are known as prey particles. The velocity of prey particles is affected by their position [1, 10]. PSO has fast computation and its implementation is also very easy. It provides high searching speed and via only few parameters its convergence can be controlled. It has certain disadvantages as its convergence depends on chosen parameters. In a case of wrong selection of PSO parameters, PSO may trap into local minimum. This results into premature convergence and local stagnation which are major drawbacks. Another disadvantage of PSO is that sometimes it losses its global searching capability. It occurs when all the particles (swarm) come together at same time and find it difficult to escape from this accumulation point. To overcome these limitations of PSO, PPO has been proposed by Silva et. al. [2, 6].

PPO solves the local stagnation problem of PSO due to the presence of predator. PPO provides better results when applied to multidimensional, multimodal problems. As it may be possible that a good position achieved now may not be good position in future, so to solve this problem PPO keeps the particles in motion hence, can be applied to data clustering problems [6]. PPO provides comprehensive set of results and better performance than PSO. The objective of this paper is to design a Band Stop FIR digital filter by using PPO. The paper has been organized in five sections. Section II formulates the FIR digital filter design problem. Algorithm of PPO has been outlined in Section III. The proposed algorithm has been evaluated and simulation results have been compared with PSO [8] in Section IV. The conclusion and discussion have been carried out in Section V.

II. FIR DIGITAL FILTER DESIGN PROBLEM

FIR is a finite impulse response filter which has finite number of non-zero terms in the sequence of its impulse response. FIR filter has linear phase response and it does not require any feedback connection. The output of FIR filter depends on the past, present and future samples of input. A FIR digital filter is characterized by the following difference equation:

$$y(m) = \sum_{k=0}^{M-1} b_k \, x(m-k) \tag{1}$$

where $x(m)$ is filter input, $y(m)$ is filter output,, b_k is set of filter coefficients and M is the filter order. The transfer function of FIR filter is given by Equ. 2:

$$H(z) = \sum_{n=0}^{N} h(n) \, z^{-n} \tag{2}$$

$H(z)$ is frequency domain representation of impulse response, $h(n)$ is time domain representation of impulse response and N is filter order. The number of filter coefficients is one more than the order of filter i.e. $N+1$ and length of filter is also $N+1$. FIR filters are symmetrical in nature therefore, the dimension of problem is halved and only one half of the coefficients are to be calculated and optimized. At the end, $N+1$ coefficients are obtained from $(\frac{N}{2}+1)$ coefficients.

There are basically four types of filters which are determined by impulse response $h(n)$ of filter. In this paper, even symmetric Band Stop FIR digital filter has been designed. The ideal response for Band Stop filter is defined by Equ. 3:

$$H_d(e^{jw}) = \begin{cases} 0 & for\ w_{c1} \le w \le w_{c2} \\ 1 & otherwise \end{cases} \tag{3}$$

w_{c1} and w_{c2} are the cut off frequencies. The design parameters of digital FIR filter are L1-norm and L2-norm approximation error of magnitude response and magnitude of ripples of both passband and stopband. In designing procedure, some of the filter coefficients are optimized in order to have minimum L_p −norm approximation error for magnitude.

L_p − norm error is given by Equ. 4:

$$E(x) = \left\{ \sum_{i=0}^{k} \left| H_d(w_i) - \left| H(w_i, x) \right| \right|^p \right\}^{1/p} \tag{4}$$

where $H_d(w_i)$ is the desired magnitude response for ideal FIR filter and $H(w_i, x)$ is the obtained magnitude response for a given set of filter coefficients.

L1-norm error (for p=1) is given by Equ. 5:

$$e_1(x) = \left\{ \sum_{i=0}^{k} \left| H_d(w_i) - \left| H(w_i, x) \right| \right| \right\}^{1/1} \quad (5)$$

L2-norm error (for p=2) is given by Equ. 6:

$$e_2(x) = \left\{ \sum_{i=0}^{k} \left| H_d(w_i) - \left| H(w_i, x) \right| \right|^2 \right\}^{1/2} \quad (6)$$

The desired magnitude response for ideal FIR filter is given by Equ.7:

$$H_d(w_i) = \begin{cases} 1 & for\ w_i \in passband \\ 0 & for\ w_i \in stopband \end{cases} \quad (7)$$

The ripple magnitude for passband and stopband is expressed as Equ.8 and Equ. 9:

$$\delta_p(x) = {}^{max}_{w_i}\{|H(w_i, x)|\} - {}^{min}_{w_i}\{|H(w_i, x)|\}; w_i \in passband \quad (8)$$

$$\delta_s(x) = {}^{max}_{w_i}\{|H(w_i, x)|\}; w_i \in stopband \quad (9)$$

$\delta_p(x)$ represents passband ripples and $\delta_s(x)$ represents stopband ripples.

The four objective functions that are to be optimized are defined as:

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

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

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

$f_4(x) = Minimize\ \delta_s(x)$

All these four objective functions are represented by a single objective function given by Equ. 10:

$$f(x) = w_1 f_1(x) + w_2 f_2(x) + w_3 f_3(x) + w_4 f_4(x) \quad (10)$$

where w_1, w_2, w_3, w_4 are the weighting functions. This overall objective function has to be minimized for the efficient design of Band Stop FIR digital filter by using the proposed PPO algorithm.

III. PREDATOR PREY OPTIMIZATION TECHNIQUE

Predator Prey Optimization is a stochastic population based global search algorithm. PPO is an extension of Particle Swarm Optimization technique. Along with prey population (swarm) another particle is introduced in PPO known as Predator. The role of predator is to introduce diversification in the prey population so as to keep a balance between exploration and exploitation. Like PSO, prey particles search for their best position in the N- dimensional search space. After each iteration, each particle's best position is calculated and that position is assigned as the particle's personal best position. Among all the pbest positions the global best position is selected. At the end of each iteration, the position and velocity of prey particles are updated. In PPO the difference lies in the affect of predator's presence on position and velocity of prey particles.

The dynamic behaviour of predator and swarm particles is different from each other. Predator gets attracted towards the best position and with the fear of predator; prey particles run away hence results into global search for the optimum solutions. Predator reduces the chance of convergence to local sub-optima as it maintains diversity in population. Therefore premature convergence is avoided in PPO. The balance between exploitation and exploration is maintained by managing the frequency and strength of predator and swarm's interaction. A new term known as Predator Fear has been introduced in PPO which controls the impact of predator on swarm population. Due to presence of predator, prey particles tend to change its velocity in one of the available N- dimensions. Predator fear represents the probability of this velocity change [2, 6].

Opposition based strategy has been employed in PPO. Learning based on the opposition was proposed by Tizhoosh. This strategy involves simultaneous consideration of estimate and its corresponding opposite estimate which results into better approximation of the optimal solutions. In Opposition based strategy, convergence speed is increased as it uses the opposite numbers during the random initial population generation. Results obtained through opposition based strategy are nearer to optimal solutions than the results produced by a purely random method [3]. The opposition based strategy is represented by Equ. 11:

$$x_{i+L,j}^{t} = x_{j}^{min} + x_{max}^{j} - x_{ij}^{t} \qquad (j = 1,2, \dots \dots, S; i = 1,2, \dots \dots L) \tag{11}$$

where x_{min}^{j} and x_{j}^{max} represents the lower and upper limits of filter coefficients.

Initialization of Prey and Predator Position and Velocity

Positions of predator and prey particles have been chosen as the decision variables and have been randomly initialized within their upper and lower limits.

$$x_{ik}^{0} = x_{i}^{min} + R_{ik}^{1}\left(x_{i}^{max} - x_{i}^{min}\right) \left(i = 1,2, \dots .. S; k = 1,2, \dots .. M_p\right) \tag{12}$$

$$x_{Pi}^{0} = x_{i}^{min} + R_{t}^{2}\left(x_{i}^{max} - x_{i}^{min}\right) \ (i = 1,2, \dots . S) \tag{13}$$

where M_p is number of prey particles. R_{ik}^{1} and R_{t}^{2} are the random numbers and their value lies between 0 and 1. x_{i}^{min} and x_{i}^{max} are the range of i^{th}decision variables.

Second decision variables are the velocities of prey (V_{ik}^{0}) and predator (V_{Pi}^{0}). These decision variables have also been initialized within their predefined range.

$$V_{ik}^{0} = V_{i}^{min} + R_{ik}^{1}\left(V_{i}^{max} - V_{i}^{min}\right) \ \left(i = 1,2, \dots . S; k = 1,2, \dots \dots M_p\right) \tag{14}$$

$$V_{Pi}^{0} = V_{i}^{min} + R_{i}^{2}\left(V_{Pi}^{max} - V_{Pi}^{min}\right) \ \ (i = 1,2, \dots S) \tag{15}$$

The maximum and minimum prey velocities are given by Equ.16 and Equ. 17:

$$V_{i}^{min} = -\alpha\left(x_{i}^{max} - x_{i}^{min}\right) \ (i = 1,2, \dots \dots S) \tag{16}$$

$$V_{i}^{max} = +\alpha\left(x_{i}^{max} - x_{i}^{min}\right) \ (i = 1,2, \dots .. S) \tag{17}$$

α is taken as 0.25. Maximum and Minimum velocities of prey particles can be achieved by varying the value of α .

Evaluation of Predator Velocity and Position

At the end of each iteration the position and velocity of predator are updated according to Equ. 18 and Equ. 19:

$$V_{Pi}^{t+1} = A_{c4}(GPbest_{i}^{t} - P_{Pi}^{t}) \quad (i = 1,2, \dots . S) \tag{18}$$

$$x_{Pi}^{t+1} = x_{Pi}^{t} + V_{Pi}^{t+1} \quad (i = 1,2, \dots \dots . S) \tag{19}$$

where $GPbest_{i}^{t}$ is the global best position of prey and A_{c4} is a random number and its value lies between 0 and its upper limit.

Evaluation of Position and Velocity of Prey

The velocity and position of prey particles are updated by using following equations after each iteration:

$$V_{ik}^{t+1} = \begin{cases} wV_{ik}^{t} + A_{c1}R_1(xbest_{ik}^{t} - x_{ik}^{t}) + A_{c2}R_2(GPbest_{ik}^{t} - x_{ik}^{t}) & ; P_f \le P_f^{max} \\ wV_{ik}^{t} + A_{c1}R_1(xbest_{ik}^{t} - x_{ik}^{t}) + A_{c2}R_2(GPbest_{ik}^{t} - x_{ik}^{t}) + A_{c3}\, a(e^{-be_k}) & ; P_f > P_f^{max} \end{cases}$$

$$(i=1,2,\dots,S;\ k=1,2,\dots,M_p) \tag{20}$$

$$x_{ik}^{t+1}=x_{ik}^{t}+c_{fc}V_{ik}^{t+1} \quad (i=1,2,\dots,S;\ k=1,2,\dots, M_p)\ (i=1,2,\dots S;\ k=1,2,\dots M_p) \tag{21}$$

A_{c1} and A_{c2} are acceleration constants. $xbest_{ik}^{t}$ is the local best position and $GPbest_{ik}^{t}$ is the global best position of prey. R_1 and R_2 are the random numbers having value between 0 and 1. A_{c3} is a random number having value between 0 and 1. $a(e^{-be_k})$ represents the predator effect which increases exponentially with proximity. Whenever prey goes closer to predator this exponential term introduces disturbance in the swarm population. a is a measure of maximum amplitude of predator effect over prey. b maintains control over the distance at which predator effect is present. e_k is defined as the distance between prey position and predator position.

$$e_k = \sqrt{\sum_{i=1}^{S}(x_{ik} - x_{Pi})^2} \tag{22}$$

w is an inertia parameter. Faster convergence is achieved by decreasing the value of w, while predator maintains diversity in the swarm population.

$$w = [w^{max} - (w^{max} - w^{min})(t/t_{max})] \tag{23}$$

The constrict factor is defined by Equ. 24:

$$C_{fc} = \begin{cases} |2-\varphi - \sqrt{\varphi^2 - 4\varphi}| & if\ \varphi \geq 4 \\ 1 & if\ \varphi < 4 \end{cases} \tag{24}$$

There is a possibility that prey particles may violate the prescribed limits of their position and velocity. This violation can be controlled by Equ. 25:

$$V_{ik}^t = \begin{cases} V_{ik}^t + R_3 V_i^{max} & if\ V_{ik}^t < V_i^{min} \\ V_{ik}^t - R_3 V_i^{max} & if\ V_{ik}^t > V_i^{min} \\ V_{ik}^t;\ no\ violation\ of\ limits \end{cases} \tag{25}$$

These equations are applied repeatedly until the limits are satisfied.

Algorithm for Predator Prey Optimization

1. Initialize the PPO parameters i.e. population size (M_p), acceleration constants (A_{c1}, A_{c2}), stopping criteria, maximum and minimum values of velocity and positions of prey particles (V_i^{max}) and predator (V_{Pi}^{max}), maximum predator fear factor (P_f^{max}).
2. Initialize the prey position and velocity.
3. Initialize the predator position and velocity.
4. Apply the opposition based strategy.
5. Calculate the objective function.
6. Select M_p best preys from the total $2M_p$ preys.
7. Compute the personal best value for each particle and among the pbest values select the global best value.
8. Update velocity and position of predator by using Equ. 18 and Equ.19.
9. Randomly generate the predator fear factor between 0 and 1.
10. IF (predator fear > maximum predator fear)
    THEN
    Position and velocity of prey particles are updated with predator affect.
    ELSE
    Position and velocity of prey particles are updated without predator affect.
    ENDIF.
11. Again calculate the objective function.
12. Update local best positions of all the prey particles.
13. Compute the global best value of prey particles based on fitness.
14. IF (stopping criterion is satisfied)
    THEN
    STOP
    ELSE
    Go to step 8.
    ENDIF.

IV. SIMULATION RESULTS

In this section simulation results performed in MATLAB have been discussed. Predator Prey Optimization technique has been implemented for the designing of Band Stop Finite Impulse Response digital filter. The Band Stop FIR digital filter has been designed by setting 200 equally spaced points within the frequency domain [0, π]. Table 1 indicates the conditions for the designing of Band Stop FIR digital filter.

Table 1: Design Conditions for Band Stop FIR Digital Filter

Filter Type	Pass Band	Stop Band	Maximum Value of H(w, x)
Band Stop	$0 \leq \omega \leq 0.25\pi$ $0.75\pi \leq \omega \leq \pi$	$0.4\pi \leq w \leq 0.6\pi$	1

The values of various design parameters used in PPO algorithm are given in Table 2. PPO has been applied at orders from 16 to 32 and objective function has been computed at these orders. Table 3 indicates that objective function has minimum value for filter order 26 hence, Band Stop FIR digital filter has been designed at order 26.

Table 2: PPO Design Parameters

Sr. No.	Parameter	Value
1	Iterations	200
2	A_{c1} , A_{c2}	2.0
3	w^{max}	0.4
4	w^{min}	0.1
5	Population Size (M_p)	100
6	P_f	0.7
7	P_f^{max}	1.0
8	w_3, w_4	10

Table 3: Objective Function at Different Orders of Band Stop FIR digital filter

Sr. No.	Order of filter	Objective function
1	16	4.388302
2	18	3.693828
3	20	1.912428
4	22	1.920977
5	24	2.094683
6	26	1.046134
7	28	8.50256
8	30	17.26267
9	32	57.03867

Fig.1 indicates the objective function at filter orders from 16 to 32. Fig. 2 shows the variation in objective function with iterations at filter order 26 and it is evident from the graph that objective function becomes stable after 60 iterations.

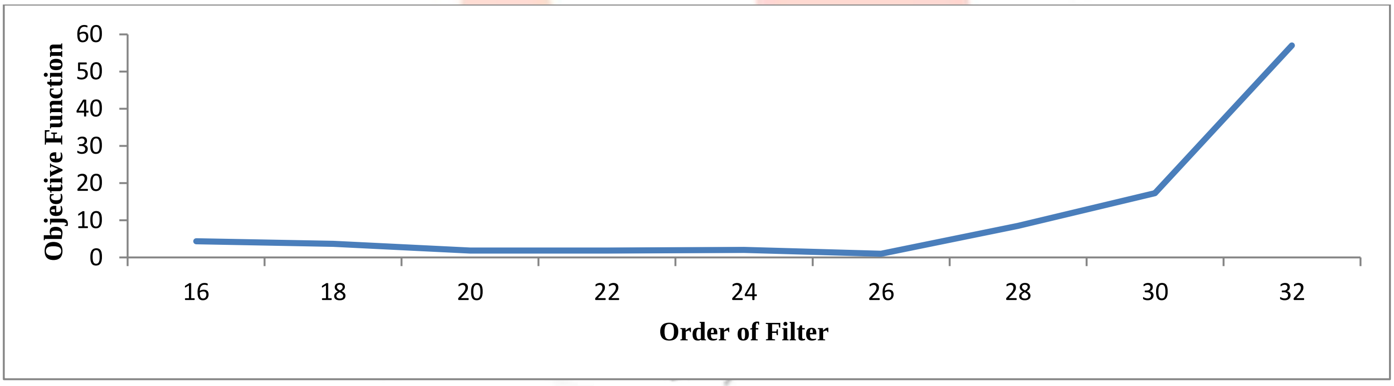

Figure 1: Order of filter versus Objective Function of Band Stop FIR digital filter

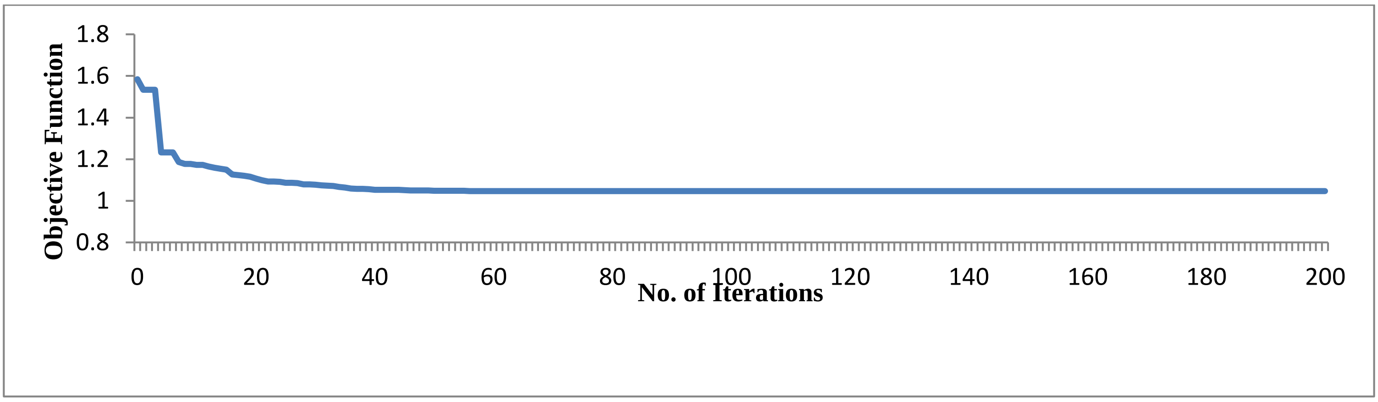

Figure 2: Objective Function versus No. of Iterations of Band Stop FIR digital filter at order 26

The comparison of obtained results with PSO [8] has been carried out. It is evident from Table 4 that PPO provides better results than PSO in terms of minimum value of performance parameters i.e. L1-norm error $e_1(x)$, L2-norm error $e_2(x)$, Passband ripples $\delta_p(x)$, Stopband ripples $\delta_s(x)$; signifying the effectiveness of PPO.

Table 4: Comparison of PPO results with PSO results of Band Stop FIR digital filter at order 26

Sr. No.	Technique	Filter Order	Objective Function	L1-norm error $e_1(x)$	L2-norm error $e_2(x)$	Passband ripples$\delta_p(x)$	Stopband ripples$\delta_s(x)$
1	PPO	26	1.046134	0.558738	0.064590	0.026624	0.015197
2	PSO [8]	26	1.434685	0.734073	0.088525	0.042746	0.017637

PARAMETER TUNING

Parameter tuning provides further reduction in the value of objective function. The two control parameters: Population size (M_p) and Acceleration constants (A_{c1} ,A_{c2}) have been varied. Population size has been varied from 50 to 110. Table 5 indicates the obtained objective function at different population size. Minimum objective function has been achieved at population size (M_p) of 100.

Table 5: Objective Function versus Population size of Band Stop FIR digital filter at order 26

Sr. No.	Population Size (M_p)	Objective Function
1	50	1.046187
2	60	1.046493
3	70	1.046187
4	80	1.046287
5	90	1.046232
6	100	1.046134
7	110	1.046378

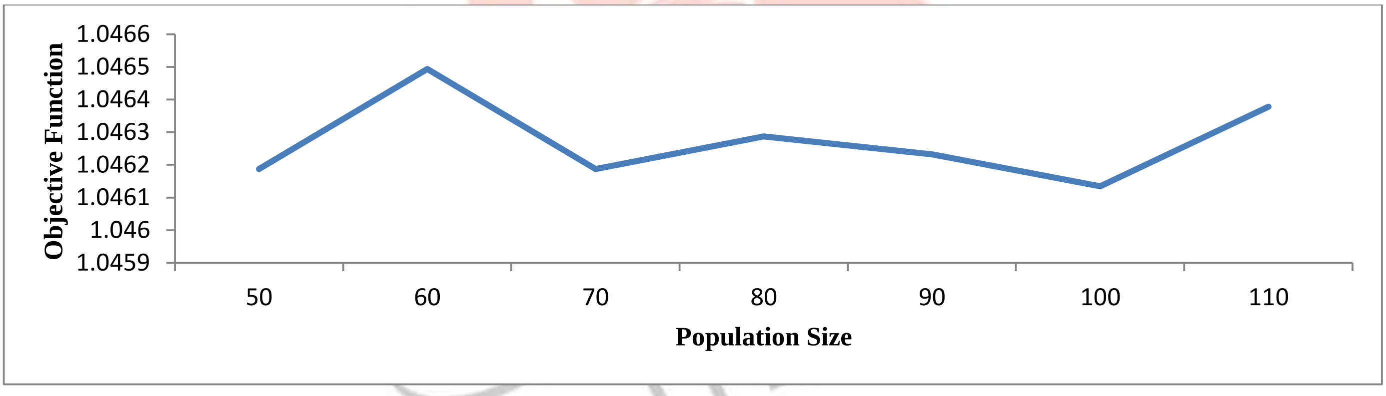

Figure 3: Objective Function versus Population Size for Band Stop FIR digital filter at order 26

Acceleration constants (A_{c1} ,A_{c2}) have been varied from 1.0 to 3.5 in steps of 0.5 as shown in Table 6. It is evident from the Table 6 and Fig. 4 that objective function has minimum value at A_{c1} and A_{c2} equal to 2.0.

Table 6: Objective Function versus Acceleration Constants (A_{c1} ,A_{c2}) of Band Stop FIR digital filter at order 26

Sr. No.	Acceleration Constants (A_{c1} ,A_{c2})	Objective Function
1	1.0	1.095716
2	1.5	1.055244
3	2.0	1.046134
4	2.5	1.046150
5	3.0	1.046675
6	3.5	1.050132

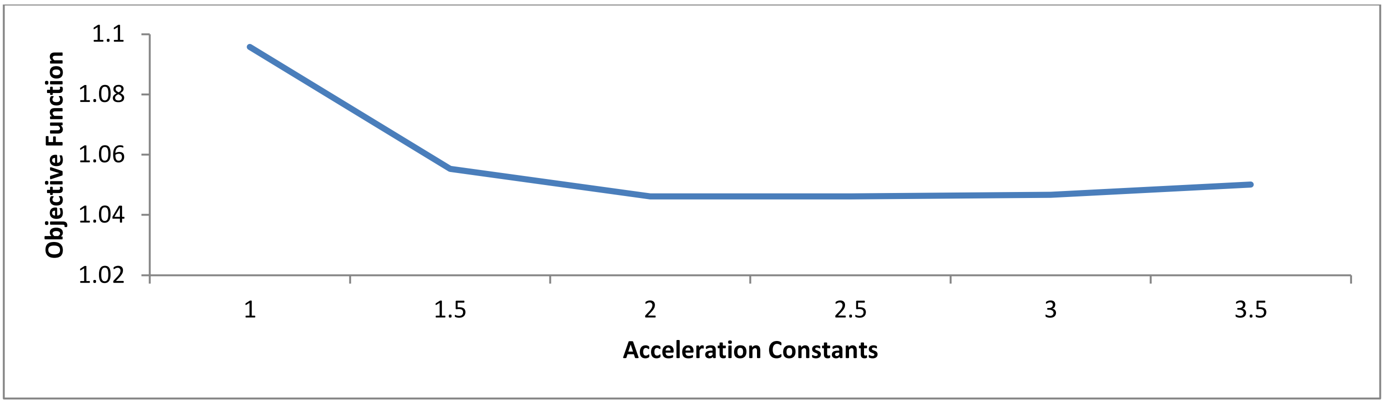

Figure 4: Objective Function versus Acceleration Constants of Band Stop FIR digital filter at order 26

Thus, the designed Band Stop FIR digital filter has minimum objective function at filter order 26, population size (M_p) of 100 and acceleration constants (A_{c1} , A_{c2}) equal to 2.0. The obtained optimized coefficients of Band Stop FIR digital filter at order 26 have been summarized in Table 7.

Table 7: Optimized Coefficients of Band Stop FIR digital filter at Order 26

Sr. No.	No. of Coefficients	Value of Coefficients
1	C(0)=C(26)	0.010457
2	C(1)=C(25)	0.003161
3	C(2)=C(24)	-0.022219
4	C(3)=C(23)	-0.003438
5	C(4)=C(22)	0.005314
6	C(5)=C(21)	-0.001396
7	C(6)=C(20)	0.052633
8	C(7)=C(19)	0.006445
9	C(8)=C(18)	-0.097783
10	C(9)=C(17)	-0.004751
11	C(10)=C(16)	0.010775
12	C(11)=C(15)	-0.003645
13	C(12)=C(14)	0.541758
14	C(13)	0.008687

After tuning the control parameters the magnitude response and phase response of the designed Band Stop FIR filter have been computed. Fig. 5 indicates the graph between magnitude response and normalized frequency. Fig. 6 depicts the magnitude response in db verses normalized frequency. Graph for variation in phase with normalized frequency has been shown in Fig. 7.

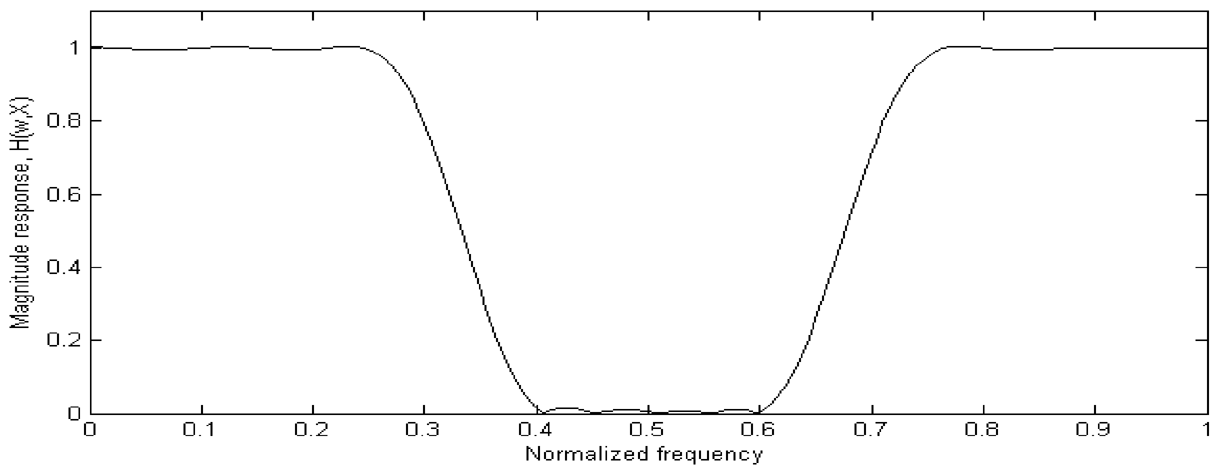

Figure 5: Magnitude response of Band Stop FIR digital filter at order 26

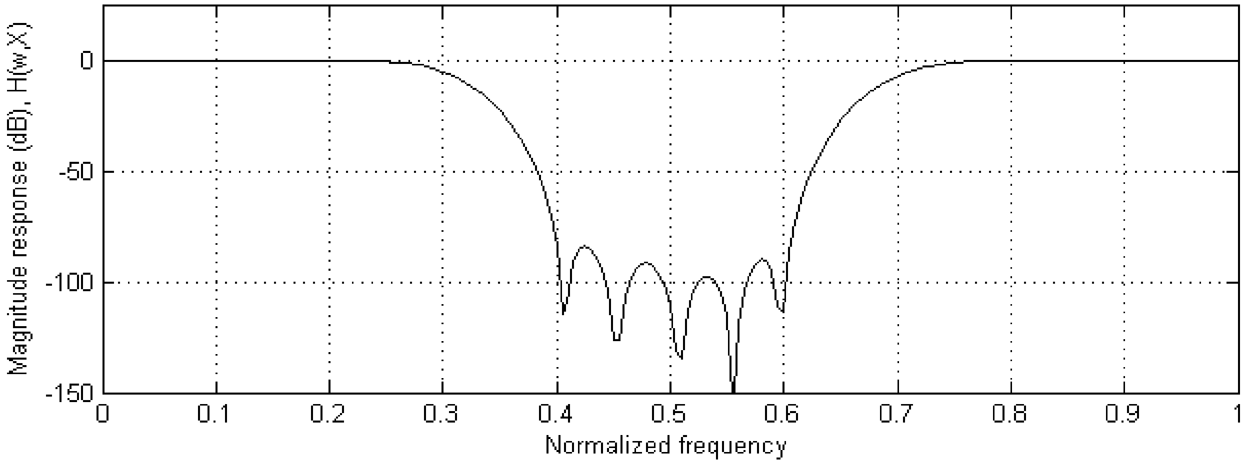

Figure 6: Magnitude response in db of Band Stop FIR digital filter at order 26

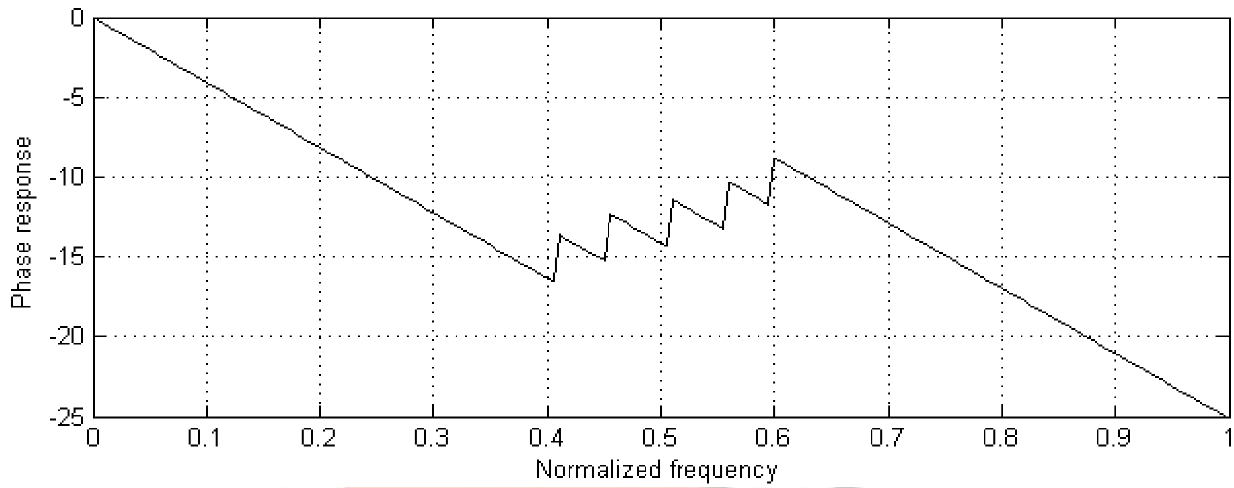

Figure 7: Phase response of Band Stop FIR digital filter at order 26

After implementing the PPO algorithm for Band Stop FIR digital filter at order 26 the maximum, minimum and average values of objective function along with standard deviation have been calculated. These values have been formulated in Table 8.

Table 8: Maximum, Minimum, Average value of Objective Function with Standard Deviation of Band Stop FIR digital filter at order 26

Sr. No.	Maximum Objective Function	Minimum Objective Function	Average Value Of Objective Function	Standard Deviation
1	2.529446	1.046134	1.31923	0.345000043

V. CONCLUSION

This paper focuses on the designing of Band Stop Finite Impulse Response digital filter by using Predator Prey Optimization technique. Simulation results have been performed in MATLAB. The objective function has been calculated at orders from 16 to 32 and objective function has minimum value at filter order 26. Therefore, Band Stop FIR digital filter has been designed at filter order 26. Parameter tuning has been carried out by varying the values of acceleration constants (A_{c1} , A_{c2}) and population size (M_p) in order to have more optimized filter coefficients. With population size (M_p) of 100 and acceleration constants (A_{c1} , A_{c2}) equal to 2.0; minimum objective function has been obtained. Maximum stopband attenuation of 36 db has been achieved. The obtained value of standard deviation is 0.345000043 which less than 1 authenticating the robustness and ruggedness of filter. Performance assessment of the obtained results has been carried out by doing comparison with PSO [8]. Simulation results confirms that PPO is an efficient technique for designing the Band Stop FIR digital filter under the prescribed design conditions and PPO outperforms PSO in terms of global search and convergence speed. Similarly, PPO can be implemented for the designing of low pass, high pass and band pass FIR digital filters.

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