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Heuristic Optimization Techniques for the Design of Digital FIR High Pass Filter: A Comparison

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Abstract— This paper consists of design of digital FIR high pass filter using predator prey optimization and hybrid predator prey optimization (HPPO) technique. HPPO is a combination of predator prey optimization (PPO) and exploratory search where Predator prey optimization is a global search method and exploratory move is a local search method. Local stagnation is possible in PSO but there is no local stagnation in PPO because prey particles always try to attain suitable position to avoid predator effect. In exploratory move solution is fine tuned in local search space. The optimal filter design parameters can be obtained using HPPO method which improves the capability to explore and exploit the search space at local and global level. Results authenticate that HPPO method is better than PPO for the design of higher order high pass digital FIR filters.

Keywords—High Pass (HP), Finite Impulse Response (FIR) Filter, Hybrid Predator Prey Optimization (HPPO), Predator Prey Optimization (PPO), Exploratory Move (EM)

I. Introduction

Filter is an electrical circuit or procedure that passes certain frequencies and removes some unwanted frequencies from the signal. Filters are used for signal separation and signal restoration. Depending on the type of input, filters are classified as analog filters and digital filters. Analog filters work on analog signals which are continuous in nature and defined by linear differential equations. Digital filter is a structure that performs numerical operations on sampled, discrete-time signal and implemented using digital logic components like adders, delays and subtractors, etc. Depending on the frequency range filters are classified as:

a) Low pass filter which allows frequency up to cut-off frequency
b) High pass filter which allows frequency above cut-off frequency
c) Band pass filter which allows to transmit input frequency in particular range
d) Band stop filter which rejects the frequency in particular range [1]

Depending on the impulse response Digital Filters are classified as

- Finite Impulse Response (FIR) Filter
- Infinite Impulse Response (IIR) Filter

FIR stands for finite impulse response, which means their impulse response is of finite length. In FIR filters current output depends on previous and present values of the input series but not on the previous output series. They are also called non recursive filters or feed forward filters because it does not use past output. FIR filter is symmetrical due to which coefficients are symmetrical. FIR filter have exactly linear phase and these filters are stable. FIR filters are used for tapping of higher order. Disadvantage of FIR filter is that it does not produce sharp cut-off. IIR stands for infinite impulse response. It is called recursive filters or feedback filters because output depends on not only past and present input series but also on the past output. IIR filter preserves order and stability of analog signal and have a rational transfer function. IIR filters do not acquire linear phase characteristics and became unstable at higher orders therefore FIR filters are preferred at higher order [2].

Various techniques to design digital FIR filters are: window method, frequency sampling and optimization. Window method is used to change infinite sequence into finite impulse response sequence. First, a proper ideal frequency selective response is chosen and then it is truncated to obtain the desired FIR filter. Due to its simplicity and efficiency, window method is preferred. Frequency sampling method is very easy but the designed filter has small attenuation in stop band and control over the frequency domain characteristics is not possible [3]. Frequency sampling method also gives errors.

Therefore Optimization technique is used for designing filter. In optimization algorithm parameters are tuned so as to achieve best results. Number of methods has been proposed for optimization such as genetic algorithms (GAs), evolutionary strategy, ant colony optimization, differential evolution, particle swarm optimization (PSO), predator prey optimization (PPO) etc [6]. Sonika et.al implemented Hamming window method, Parks-McClellan method and Genetic Algorithm (GA) for the design of Low pass digital FIR filter and concluded that filter design using GA is best because it has less transition bandwidth, small ripples in pass band and stop band and better phase response as compared to other techniques. Phase delay is minimum in GA based methods [4].

Kennedy and Eberhart [11] have introduced the particle swarm optimization method that is a global search technique. The PSO has simple concept, easy to implement, fast computation and robust search ability. In comparison to other EAs, PSO has advantages in searching speed and precision [1]. PSO has some shortcomings such as its convergence behaviour which depends upon its parameters. Sometimes PSO gets trapped in local minimum value. When PSO is applied to high-dimensional optimization problems, premature convergence occur which reduces optimization precision or even failure and lose its global search ability. For overcoming these problems a predator-prey model has been developed. He concluded that predator-prey method is more beneficial as keeping the particles moving is highly important, because a good position obtained now may not be good in future. In PPO model, predator has been searching best position globally and preys try to escape from predator, which prevents premature convergence [12].

Yadwinder et.al presented the hybrid of GA and PSO for low pass FIR filter which is better than individual GA and PSO in terms of efficiency and numerical stability. But if the initial parameters are not chosen correctly then it results in trapping in local minima [5]. In the proposed method for the design of high pass digital FIR filter Hybrid Predator Prey Optimization (HPPO) method has been employed in which exploratory move has been hybridized with PPO. HPPO method explores the search space globally as well locally. The values of the filter coefficients have been optimized to achieve minimum magnitude error and ripple magnitude for proposed optimization problem.

II. PROBLEM FORMULATION

FIR filters are digital filters that have finite impulse response and they do not contain any feedback therefore called as non-recursive digital filters. Linear phase FIR filter is designed because it is symmetrical, due to which half of the coefficients are updated by any algorithm and then they are joined to form other half [8]. The difference equation of FIR filter is 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 are coefficients, M is 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 FIR filter is designed by optimizing the coefficients in such a way that the approximation error function is minimised. The magnitude response is specified at K equally spaced discrete frequency points in pass-band and stop-band.

e_1 (x) - absolute error of magnitude response

e_2 (x) – mean error of magnitude response

$$e_1(x) = \sum_{i=0}^{K} \left| H_d(\omega_i) - |H(\omega_i, x)| \right| \quad (3)$$

$$e_2(x) = \sum_{i=0}^{K} \left(\left| H_d(\omega_i) - |H(\omega_i, x)| \right| \right)^2 \quad (4)$$

Ideal magnitude response is given below:-

$$H_d(\omega_i)\begin{cases} 1 \ for \ \omega_i \in passband \\ 0 \ for \ \omega_i \in stopband \end{cases}$$

H(ω_i,x) is obtained magnitude response of the approximate filter.

The ripple magnitudes of pass-band and stop-band are to be minimized which are given by δ_p (x) and $\delta_s(x)$ respectively

$$\delta_p(x) = \max\{ |H(\omega_i,x)| \} - \min\{ |H(\omega_i,x)| \} \quad (5)$$

$$\delta_s(x) = \max\{ |H(\omega_i,x)| \} \quad (6)$$

All objective functions for optimization are:

$f_1(x)$ = Minimize $e_1(x)$ (7a)

$f_2(x)$ = Minimize $e_2(x)$ (7b)

$f_3(x)$ = Minimize $\delta_p(x)$ (7c)

$f_4(x)$ = Minimize $\delta_s(x)$ (7d)

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

$$\text{Minimize } f(x) = \sum_{j=1}^{4} \omega_j f_j(x) \quad (8)$$

where ω_j are weighting functions.

III. OPTIMIZATION TECHNIQUES

A. Predator Prey Optimization

In Predator Prey Optimization, predator effect is added to particle swarm optimization (PSO). PSO is a population based search technique in which swarm intelligence like fish schooling, bird flocking are used. In PSO particle changes its position with time based on its own experience and neighbouring experience. The predator has different nature than swarm particles and predator attracts most excellent persons in a group and repell other particles. Prey particles always attain best positions to save itself from predator's attack. In PPO model, predator is responsible for worldwide search whereas preys search for space avoiding predator effect, which avoids meeting of local optima. Exploration and exploitation is maintained by controlling the interactions between predator and prey. PPO model also helps to avoid premature convergence [9].

B. Hybrid Predator Prey Optimization

Predator Prey Optimization has been combined with Exploratory Move and Opposition based method to form Hybrid Predator Prey Optimization (HPPO). Hybridisation is the combination of two or more optimization techniques into a single algorithm. PPO is a global search and Exploratory Move is to fine tune the solution. Opposition based method is used so as to start with the best solution.

Equations of HPPO

Total population consists of n_p preys and a single predator. The Initial positions of preys and predator are initialized between upper and lower limits as x_{ik}^0 and x_{pi}^0 respectively.

$$x_{ik}^0 = x_i^{min} + R_{ik}^1(x_i^{max} - x_i^{min})(i = 1,2 \dots .S; k = 1,2 \dots .N_p) \quad (9)$$

$$x_{pi}^0 = x_i^{min} + R_i^2(x_i^{max} - x_i^{min})(i = 1,2 \dots .S) \quad (10)$$

where x_i^{min} and x_i^{max} are representing the lower and upper limit of ith decision variables; R_{ik}^1 and R_i^2 are uniform random numbers having value between 0 and 1.

Prey and predator velocities are given below:-

$$V_{ik}^0 = V_i^{min} + R_{ik}^1\left(V_i^{max} - V_i^{min}\right)\left(i = 1,2 \ldots .S; k = 1,2 \ldots .N_p\right) \quad (11)$$

$$V_{pi}^0 = V_{pi}^{min} + R_i^1\left(V_{Pt}^{max} - V_{Pi}^{min}\right)(i = 1,2 \ldots .S) \quad (12)$$

Where minimum and maximum prey velocities are

$$V_i^{min} = -\alpha(x_i^{max} - x_i^{min})(i=1,2\ldots.S) \quad (13)$$

$$V_i^{max} = +\alpha(x_i^{max} - x_i^{min})(i=1,2\ldots.S) \quad (14)$$

By varying value of α(taken as 0.25), minimum and maximum velocities for preys are obtained.

The equation of velocity and position of predator for $(t+1)^{th}$ iteration is given by:

$$V_{pi}^{t+1} = C_4\left(GPbest_i^t - P_{pi}^t\right) \ (i = 1,2, \ldots S) \quad (15)$$

$$x_{pi}^{t+1} = x_{pi}^t + V_{pi}^{t+1} \quad (i = 1,2,....,S) \quad (16)$$

where, $GPbest_i^t$ is best global prey position of i^{th} variable; C_4 is random number ranging from 0 to upper limits; x_{pi} is element of position of predator; V_{pi} is velocity.

The equation of velocity and position of prey particle for $(t+1)^{th}$ iteration is given by:

$$v_{ik}^{t+1} = \begin{cases} wV_{ik}^t + C_1R_1(xbest_{ik}^t - x_{ik}^t) + C_2R_2(Gxbest_{ik}^t - x_{ik}^t) & ; P_f \le P_f^{max} \\ wV_{ik}^t + C_1R_1(xbest_{ik}^t - x_{ik}^t) + C_2R_2(Gxbest_{ik}^t - x_{ik}^t) + C_3a(e^{-be_o}); & P_f > P_f^{max} \end{cases} \quad (17)$$

$$x_{ik}^t = x_{ik}^t + c_e V_{ik}^t \quad (18)$$

where, (i=1,2,.....S; k=1,2,.......N_p)

C_1, C_2 is acceleration constant, *w* is weight of inertia, R_1, R_2 is random number having value in range [0,1], $xbest_{ik}^t$ is local position of i^{th} population, *a* has maximum amplitude of predator effect on the prey, *b* is controlling factor, C_3 is random number(0-1), e_k is Euclidean distance between the position of prey and predator position for k^{th} population given as:

$$e_k = \sqrt{\sum_{i=1}^{S}(x_{ik} - x_{pi})^2} \quad (19)$$

The inertia weight is calculated by adopting following relation and it shows the decreasing trend as the iteration progresses.

$$w = \left[w^{max} - \left(w^{max} - w^{min}\right)\left(\frac{t}{t_{max}}\right)\right] \quad (20)$$

C_{fc} is the constrict factor and is defined by the following equation:

$$C_{fc} = \begin{cases} \{|2 - ø - \sqrt{ø^2 - 4ø}| & \text{if } ø \ge 4 \\ 1 & \text{if } ø < 4 \end{cases} \quad (21)$$

The elements of prey positions x_{ik}^t and velocities V_{ik}^t may violate their limits. This violation is set by updating their values on violation either at lower or upper limits.

$$V_{ik}^t = \begin{cases} V_{ik}^t + R_3V_i^{max}; if V_{iki}^t < V_i^{min} \\ V_{ik}^t - R_3V_i^{max}; if V_{iki}^t > V_i^{min} \\ V_{ik}^t \quad ; no\ violation\ of\ limit \end{cases} \quad (22)$$

where R_3 is any uniform random number between 0 and 1. The process is repeated till the satisfying the limits. Similarly, predator velocity limits are adjusted.

C. Opposition Based Method

Opposition based method has been employed so as to start with the best solution. Initially number of preys has been doubled and then best half preys has been taken for finding the optimal solution. Opposition based method can improve the chance of starting with a better solution. Opposition based method has the potential to accelerate convergence [10].

$$x_{i+L,j}^{t} = x_j^{min} + x_j^{max} - x_{ij}^{t} \quad (23)$$

(j =1,2,….S; i=1,2…..L)

where x_j^{min} and x_j^{max} are lower and upper limits of filter coefficients.

D. Exploratory Move

In exploratory move, each current point obtained by PPO algorithm is disturbed in positive and negative directions along each variable taken one at a time and then the best point is obtained. If the best point found at the end of all disturbances is a new point then exploratory move is a success else it is a failure. The best point obtained is the outcome of the exploratory move [7]. Filter coefficient x is initialized as follows:

$$x_i^n = x_i^o \pm \Delta_i u_i^j \qquad (i=1,2,\ldots\ldots\ldots, S\ ; j=1,2,\ldots\ldots\ldots, S) \quad (24)$$

$$u_i^j = \begin{cases} 1 & i=j \\ 0 & i \neq j \end{cases} \quad (25)$$

where S denotes number of variables.

The objective function denoted by $A(x_i^n)$ is calculated as follows:

$$x_i^n = \begin{cases} x_i^o + \Delta_i u_i^j & ; A\left(x_i^o + \Delta_i u_i^j\right) \leq A(x_i^o) \\ x_i^o - \Delta_i u_i^j & ; A\left(x_i^o - \Delta_i u_i^j\right) \leq A(x_i^o) \\ x_i^o & ;\ otherwise \end{cases} \quad (26)$$

where (i=1,2 ... S) and Δ_i is random for global search and fixed for local .

The process is repeated till all the filter coefficients are explored and overall minimum value is obtained as new starting point for next iteration.

E. Algorithm: - Exploratory Move

1. Select small change Δ_i and x_i^o and then compute *f* (x_i^o)
2. Initialize iteration counter, IT=0 and then increment it to IT+1.
3. IF *IP* >IP^{max} GO TO 9
4. Initialize filter coefficient counter j=0 and then increment it to j+1.
5. Find u_i^j using Eq.24 and evaluate Performance Function, $A\left(x_i^o + \Delta_i u_i^j\right)$ and $A\left(x_i^o - \Delta_i u_i^j\right)$
6. Find x_i^n using Eq.25 and evaluate *A*(x_i^n)
7. IF $(j \leq s)$, then increment j=j+1 and repeat step 5 and 6.
8. IF *A*(x_i^n) < *A*(x_i^o)
   THEN GO TO 4
   ELSE $\Delta_i = \Delta_i/1.618$ and increment IT+1 and GO TO 3 and repeat.
9. STOP

F. Algorithm:- HPPO

1. Input data viz. maximum allowed movements, swarm size, maximum and minimum limit of velocity, maximum probability fear (pf) etc.
2. Initialize prey and predator positions and velocities.
3. Apply opposition based strategy.
4. Compute augmented objective function.
5. Select n_p best preys from total 2n_p preys.
6. Assign local best position to all prey particles and then compute its global best.

7. Update velocity and position of predator according to global best value.
8. Randomly generate the probability fear in the range (0, 1)
9. IF (probability fear > maximum probability fear)

   THEN, Update velocity and position of prey with predator affect

   ELSE, Update velocity and position of prey without predator affect

   ENDIF
10. Compute augmented objective function for all prey partcles.
11. Update local best and global best position of prey particles.
12. Perform exploratory move for the refinement of global best position of prey particles.
13. Call exploratory move.

IV. DESIGN PARAMETERS

Hybrid Predator Prey Optimization (HPPO) and Predator Prey Optimization method (PPO) has been applied to design the digital FIR high pass filter, yielding optimal filter coefficients. 200 equally spaced samples are set within the range $[0,\pi]$ for the design of high pass FIR filter. Order of the filter has been varied from 20 to 44 and the algorithm is run for 100 times for each order. The range of pass-band and stop-band is taken as $0 \leq \omega \leq 0.2\pi$ and $0.3\pi\leq\omega\leq\pi$. Initially the population size (IPOP) has been taken as 100, accelerating constants C_1 and C_2 as 2.0, maximum weight (wmax) as 10. The optimized coefficients of the filter have been noted and the magnitude and phase response of FIR filter have been drawn.

A. *Comparison of HPPO and PPO*

Table I shows comparison of objective function of HPPO and PPO for different orders of high pass digital FIR filter. Order of the filter has been varied from 20 to 44 for PPO and HPPO algorithm. Fig.1 shows the graph of objective function of HPPO and PPO for different orders of filter. It is observed that objective function of high pass digital FIR filter is less for HPPO as compared to PPO for all the orders. PPO has minimum objective function for filter order 20 but gets deteriorated at higher filter order. HPPO has achieved minimum objective function for filter order 38 and has less objective function for each order as comparative to PPO. So filter order 38 has been selected for designing high pass digital FIR filter using HPPO. HPPO gives better performance than PPO. Therfore HPPO method is used for further tunning of parameters like C_1, C_2 and IPOP.

Table I: Objective function of HPPO and PPO for different filter orders

Order of the filter	objective function	
	HPPO	PPO
20	5.520973	5.522852
22	4.429965	4.433071
24	4.17736	4.204583
26	3.770306	3.782325
28	2.669924	2.683615
30	2.150152	12.51526
32	2.04764	40.24897
34	1.847153	68.18776
36	1.306942	153.6227
38	1.09574	219.6645
40	1.119972	248.6016
42	1.224103	319.9832
44	1.38808	452.625

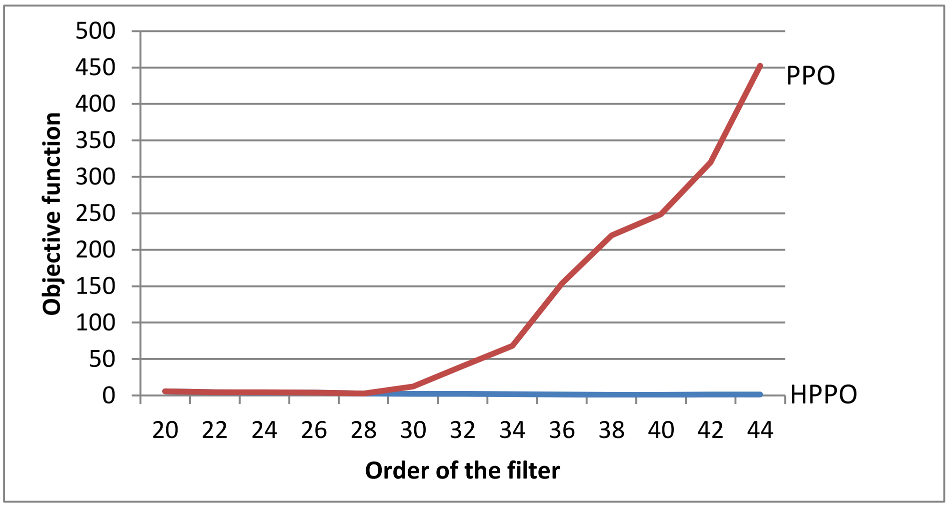

Fig 1: Comparison of objective function of HPPO and PPO for different filter orders

B. *Design Parameters of High pass filter for different orders*

The main objective of this paper is to minimize the objective function, magnitude error and Pass-band and Stop-band ripples. Table II shows the design parameters of HP digital FIR filter for different orders. Initially the objective function decreases as order of filter increases. The objective function for filter order 38 is minimum as compared to other orders and it also meets the objective of the paper. The achieved value of objective function is 1.09574, the pass-band ripple is 0.04039 and the stop-band ripple is 0.012426.

Table II: Various design parameters of High Pass FIR Filter for different order using HPPO

Filter Order	Objective Function	Magnitude Error1	Magnitude Error2	Pass-band Performance	Stop-band Performance
20	5.520973	2.665336	0.329081	0.1237	0.127002
22	4.429965	2.00954	0.255366	0.129449	0.086723
24	4.17736	1.819664	0.262302	0.150262	0.056949
26	3.770306	1.929461	0.248648	0.070479	0.088741
28	2.669924	1.403109	0.17136	0.059562	0.049983
30	2.150152	1.061748	0.1281	0.06407	0.03193
32	2.04764	0.895354	0.125207	0.082565	0.020122
34	1.847153	1.018423	0.13683	0.024213	0.044977
36	1.306942	0.707908	0.092311	0.019379	0.031293
38	**1.09574**	**0.505197**	**0.062357**	**0.040392**	**0.012426**
40	1.119972	0.424866	0.067965	0.055562	0.007153
42	1.224103	0.44976	0.079065	0.065219	0.004308
44	1.38808	0.622633	0.139413	0.006902	0.055702

C. *Variation of Objective function with population*

Fig.2 represents variation of objective function with population size where population has been varied from 60 to 140 in steps of 20 for 38 order high pass FIR filter using HPPO method. Objective function varies randomly with change in population size. Minimum value of objective function is 1.095226 which is obtained at population 60.

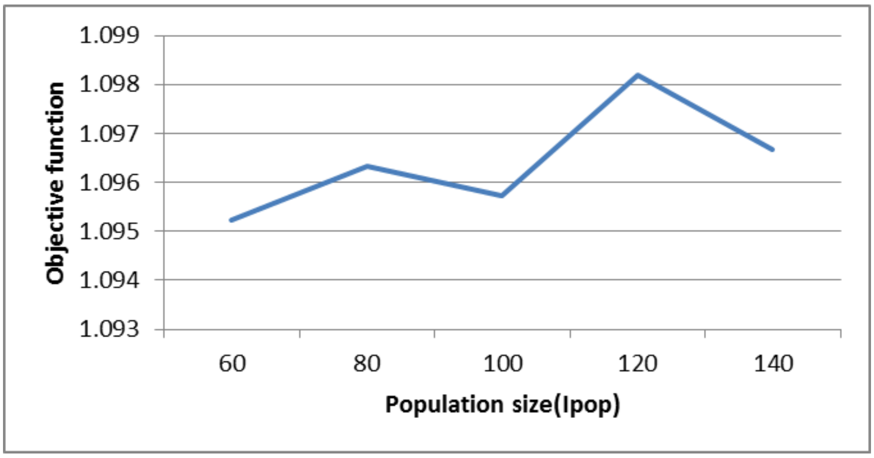

Fig. 2: Population size v/s objective function for filter order 38

D. ***Variation of Objective function with Acceleration constants***

Fig.3 represents variation of objective function with acceleration constants $C_1 = C_2$ where constants C_1 and C_2 has been varied from 1 to 3 in steps of 0.5 for 38 filter order of high pass digital FIR filter using HPPO method. Objective function shows random variation. When C_1 and C_2 is 1.5, value of objective function is minimum that is 1.094485.

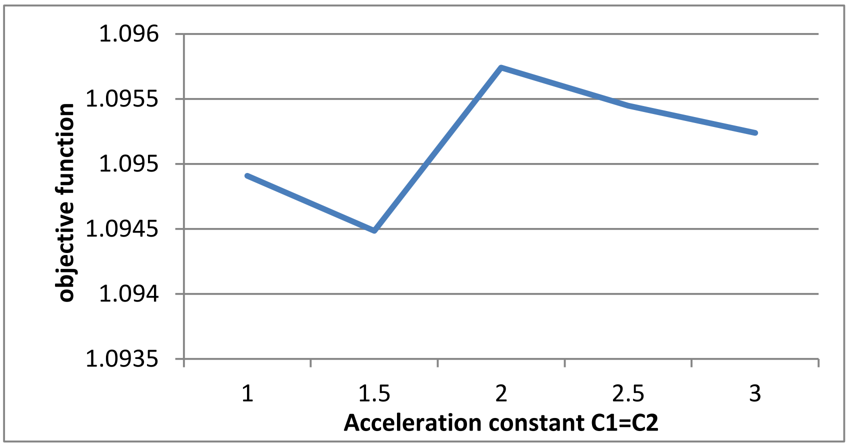

Fig. 3: Acceleration constants v/s Objective function for filter order 38

E. ***Magnitude and Phase response***

Magnitude and phase response of high pass digital FIR filter for 38 order has been obtained using MATLAB. Frequency response has been obtained from 39 filter coefficients and magnitude versus normalized frequency graph has been drawn to analyse attenuation and amplification values for different frequencies. It also determines the behaviour of filter in pass band and stop band. Fig.4 represents magnitude response versus normalized frequency. Magnitude increases above 0.7π. Fig.5 represents magnitude response in db of high pass digital FIR filter for order 38.

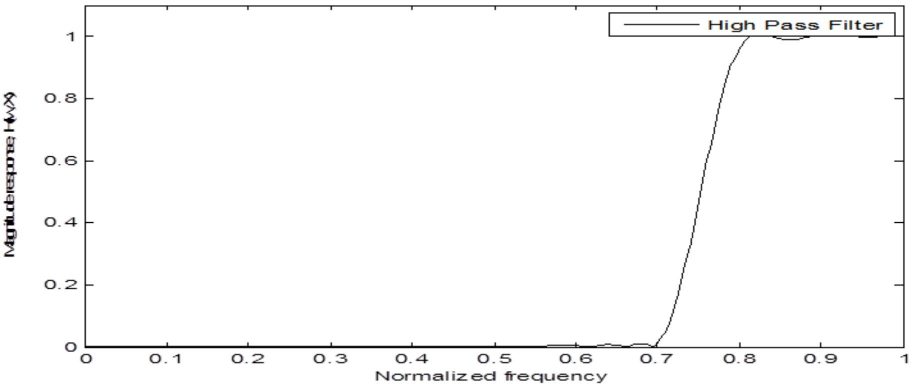

Fig. 4: Magnitude response of high pass digital FIR filter for order 38

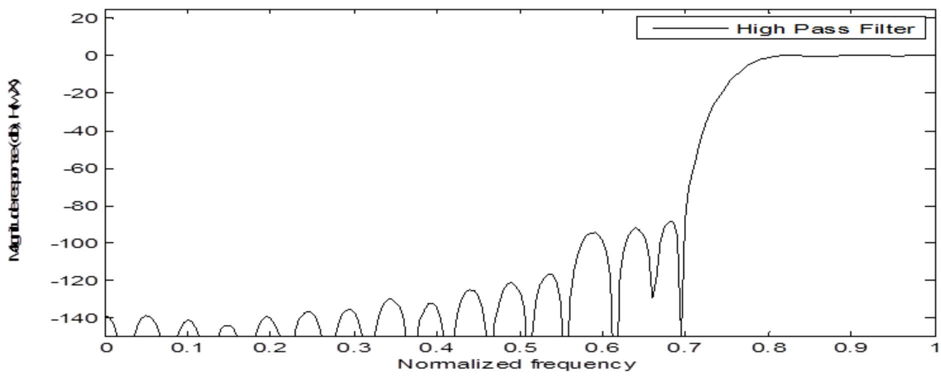

Fig. 5: Magnitude response (db) of high pass digital FIR filter for order 38

Fig.6 shows graph of phase response with normalized frequency. High pass FIR filter has linear phase above 0.7π rad/sample

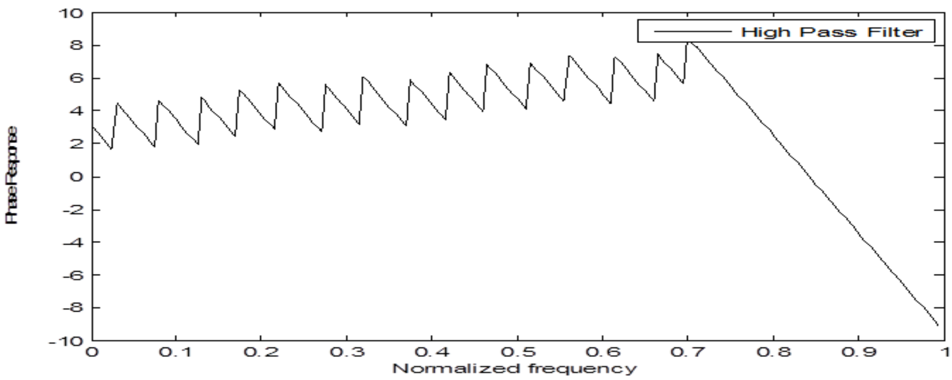

Fig. 6: Phase response of high pass digital FIR filter for order 38

IV. CONCLUSIONS

HPPO is an important optimization algorithm that shows simplicity and robustness in design of higher order high pass digital FIR filter. Hybridization of predator-prey optimization and exploratory move is superior and very much feasible to provide a powerful option for the design of high order high pass digital FIR filter. HPPO creates a balance between exploration and exploitation. On the basis of results it is seen that achieved objective function is minimum for filter order 38 when IPOP is 100 and $C_1 = C_2$ is 2. In order to obtain better results parameter tunning has been executed. Simulation results justify that HPPO algorithm has superior performance than PPO, therefore it can be extended for the design high order low pass, band pass and band stop FIR filters.

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