

Design of Digital FIR High Pass Filter using Hybrid Predator Prey Optimization

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ABSTRACT: This paper presents a novel approach for designing a digital FIR high pass filter using hybrid predator prey optimization (HPPO) algorithm. HPPO is a combination of two algorithms that are given by predator prey optimization (PPO) and exploratory move (EM). Predator prey optimization is a global search algorithm whereas exploratory move is a local search algorithm. Prey particles try to occupy safe place to save themselves from predator. Exploratory search adjusts the solution in local search space. The optimal filter design parameters have been obtained using HPPO algorithm which results in minimizing the magnitude error and ripple magnitude. The achieved results have been compared with the results obtained by hybrid differential evolution algorithm and it has been seen that filter designed using HPPO outperforms HDE in the solution quality and convergence speed.

KEYWORDS: Finite impulse response (FIR) filter; high pass (HP); hybrid predator prey optimization (HPPO); exploratory move (EM); hybrid differential evolution (HDE)

I. INTRODUCTION

Filtering is an important signal processing operation used to attenuate or boost the signal. The system performing this function is called filter. Filter is the process of eliminating some frequencies that is present at the output of the system to suppress unwanted signals and diminish background sound. 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. Digital filter is a structure that performs numerical operations on sampled, discrete-time signal. Depending on the frequency range filters are classified as low pass, high pass, band pass and band stop filter [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. FIR filter is symmetrical due to which coefficients are symmetrical. FIR filters are also called feed-forward filters or non-recursive filters which mean there is no feedback of past or future outputs to form the present outputs. FIR filter have exactly linear phase and these filters are stable. FIR filter are used for tapping of higher order. IIR stands for infinite impulse response. IIR filters are also called a feed-back filter or recursive filter which means there is feedback of past outputs to form present output. IIR filter preserves order and stability of analog signal, do not acquire linear phase characteristics and became unstable for tapping of 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. Various filters are designed using window method. Window method is used to change infinite sequence into finite impulse response sequence [3]. Different window methods are hamming window, hanning window, kaiser window etc. Frequency sampling method is very easy but the designed filter has small attenuation in stop band and control over the frequency domain is not possible and it gives error. Optimization technique is used for designing filter to overcome the

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problems faced in other techniques. Genetic algorithms (GAs), differential evolution (DE), particle swarm optimization (PSO), predator prey optimization (PPO) are some of the different optimization techniques.

II. RELATED WORK

Sonika et.al 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 [4]. Kennedy and Eberhart [13] have introduced the particle swarm optimization method that is a global search technique. PSO has advantages such as easy implementation, fast computation, high searching speed and precision. Due to its premature convergence other optimization methods may be preferred. Predator-prey model has been developed by Silva [12] and it has been concluded that predator-prey method is more beneficial as predator search global best position and preys avoid predator's attack, which prohibits premature convergence. This PPO method is not effective for design of higher order filter.

For better results hybridisation i.e combination of two or more algorithms is adopted. 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]. Rajni presented hybrid differential evolution method for the design of high pass digital FIR filter and concluded that proposed algorithm gives more accurate and better results. Hybrid differential evolution enhances the ability of global search space the local by searching local neighbourhood of global solution [10].

In this paper Hybrid Predator Prey Optimization (HPPO) method has been implemented for the design of high pass digital FIR filter. In this predator prey optimization has been hybridized with opposition based method and exploratory move. Opposition based method has been employed so as to start with the best solution. The values of the filter coefficients are optimized to achieve minimum magnitude error and ripple magnitude.

III. PROBLEM FORMULATION

FIR filters are digital filters that have finite impulse response and they do not contain any feedback. FIR is implemented using transversal filter. The transversal filter is also known as a tapped delay line filter. It consists of three basic elements that are unit delay element, multiplier and adder [6]. 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 filter order.

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.

$e_1(x)$ - absolute error of magnitude response

$e_2(x)$ - mean error of magnitude response

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

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

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Ideal magnitude response,

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

$H(\omega_i, x)$ 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 $\delta_p(x)$ 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:

$$f_1(x) = \text{Minimize } e_1(x) \quad (7a)$$

$$f_2(x) = \text{Minimize } e_2(x) \quad (7b)$$

$$f_3(x) = \text{Minimize } \delta_p(x) \quad (7c)$$

$$f_4(x) = \text{Minimize } \delta_s(x) \quad (7d)$$

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.

IV. METHODOLOGY

Predator prey optimization

In Predator Prey Optimization, predator effect is added to particle swarm optimization (PSO). PSO is a population based search technique which uses swarm intelligence like fish schooling, bird flocking. In PSO particle changes its position in accordance to time which is based on its experience and neighbouring experience. In PPO, the predator population is incorporated with the swarm particles. The predator has different nature than swarm particles and predator attracts most excellent persons in a group and repel other particles. Prey particles always attain best appropriate positions to avoid predator's attack. In PPO, predator is used to search best space globally whereas preys search for solution space escaping from predators, which avoids meeting of local optima. Exploration and exploitation is balanced and maintained by controlling the strength and frequency of the interactions between predator and prey. In PPO model, action of predator and preys helps to avoid premature convergence to local optima [7].

Hybrid predator prey optimization

Hybridisation is the combination of two or more optimization techniques into a single algorithm. Predator Prey Optimization and Exploratory Move have been combined to form Hybrid Predator Prey Optimization (HPPO). PPO is a global search and EM is a local search. PPO method hybridized with exploratory search is superior and very much feasible for design of high order digital FIR filters.

Equations of HPPO

The Initial positions of preys and predator are randomly initialized between upper and lower limits. Total population consists of preys and a single predator.

Prey and predator positions are x_{ik}^0 and x_{pi}^0

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

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

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

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Prey and predator velocities

$$V_{ik}^0 = V_i^{min} + R_i^1 (V_i^{max} - V_i^{min}) \quad (i = 1, 2, \dots, S; k = 1, 2, \dots, N_p) \quad (11)$$

$$V_{pi}^0 = V_{pt}^{min} + R_i^1 (V_{pt}^{max} - V_{pi}^{min}) \quad (i = 1, 2, \dots, S) \quad (12)$$

where minimum and maximum prey velocities are

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

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

By varying value of α , minimum and maximum velocities for preys are obtained.

Velocity and position of predator is given by:

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

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

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.

Velocity and position of prey particle for (t+1)th iteration is given by:

$$v_{ik}^{t+1} = \begin{cases} wV_{ik}^t + C_1 R_1 (xbest_{ik}^t - x_{ik}^t) + C_2 R_2 (Gxbest_{ik}^t - x_{ik}^t) & ; P_f \leq P_f^{max} \\ wV_{ik}^t + C_1 R_1 (xbest_{ik}^t - x_{ik}^t) + C_2 R_2 (Gxbest_{ik}^t - x_{ik}^t) + C_3 a (e^{-be_o}) & ; P_f > P_f^{max} \end{cases} \quad (17)$$

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

where, $(i=1, 2, \dots, S; k=1, 2, \dots, N_p)$

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

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

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 improves the chances of starting with a better solution. Opposition based method has the potential to accelerate convergence [11].

$$x_{i+N_p, j}^t = x_j^{min} + x_j^{max} - x_{ij}^t \quad (20)$$

$(j=1, 2, \dots, S; i=1, 2, \dots, N_p)$ where x_j^{min} and x_j^{max} are lower and upper limits of filter coefficients.

Exploratory move

In exploratory move, current point is perturbed in positive and negative directions along each variable one at a time and then the best point is recorded. The current point is updated to the best point after each perturbation. If the point found at the end of all perturbations is different from original point then exploratory move is a success otherwise it is a

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failure. The best point obtained is the outcome of the exploratory move [9]. The starting point obtained through random initialization is explored iteratively and filter coefficient x is initialized as follows:

$$x_i^n = x_i^o \pm \Delta_i u_i^j \quad (i=1,2,\dots,S ; j=1,2,\dots,S) \quad (21)$$

Where $u_i^j = \begin{cases} 1 & i=j \\ 0 & i \neq j \end{cases}$

S denotes number of variables.

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

$$x_i^n = \begin{cases} x_i^o + \Delta_i u_i^j & ; A(x_i^o + \Delta_i u_i^j) \leq A(x_i^o) \\ x_i^o - \Delta_i u_i^j & ; A(x_i^o - \Delta_i u_i^j) \leq A(x_i^o) \\ x_i^o & ; \text{otherwise} \end{cases} \quad (22)$$

where $(i=1,2 \dots S)$ 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.

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, $A(x_i^o + \Delta_i u_i^j)$ and $A(x_i^o - \Delta_i u_i^j)$
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

Algorithm:- Hybrid predator prey optimization

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 particles.
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.

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13. Is stopping criteria met?
No- go to step 7
Yes- Stop.

V. RESULTS

Hybrid Predator Prey Optimization (HPPO) methods have 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 60, 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 [8].

Comparison of HPPO and HDE

Table 1 shows comparison of results of HPPO and HDE for filter order 38 of high pass digital FIR filter in terms of magnitude error and ripple magnitude. Results of hybrid differential evolution method have been taken from research article by Rajni and Balraj Singh [10]. It is observed that HPPO minimizes magnitude error and ripple magnitude to a greater extent as compared to HDE. Pass band ripple is not better while stop band ripple is better due to conflicting nature of pass band and stop band. We don't compare objective function because we don't know the value of weights when results of HDE have been obtained.

Table 1: comparison of results of HPPO and HDE for filter order 38

| Type of algorithm | Magnitude Error1 | Magnitude Error2 | Pass-band Performance | Stop-band Performance |
|-------------------|------------------|------------------|-----------------------|-----------------------|
| HPPO | 0.51049 | 0.061805 | 0.040119 | 0.012174 |
| HDE[10] | 0.547658 | 0.080784 | 0.019915 | 0.030008 |

The main objective of this paper is to minimize the objective function, magnitude error and Pass-band and Stop-band ripples. Table 2 shows the design parameters of FIR HP filter for different orders. Initially the objective function decreases as order of filter increases. The objective function for order 38 is minimum as compared to other orders and it also meets the objective of the paper. Minimum value of objective function is 1.095226.

Table 2: 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 | 5.521049 | 2.684613 | 0.327797 | 0.123862 | 0.125281 |
| 22 | 4.429928 | 2.008602 | 0.255474 | 0.129347 | 0.086907 |
| 24 | 4.177486 | 1.819768 | 0.262014 | 0.149577 | 0.057742 |
| 26 | 3.770675 | 1.933169 | 0.246166 | 0.070705 | 0.088429 |
| 28 | 2.669787 | 1.396755 | 0.170581 | 0.060797 | 0.049448 |
| 30 | 2.151542 | 1.091625 | 0.129043 | 0.061737 | 0.031319 |
| 32 | 2.049935 | 0.908162 | 0.125467 | 0.082273 | 0.019305 |
| 34 | 1.842694 | 0.995647 | 0.1367 | 0.025128 | 0.045907 |

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| | | | | | |
|-----------|-----------------|----------------|-----------------|-----------------|-----------------|
| 36 | 1.307325 | 0.705226 | 0.090543 | 0.02019 | 0.030965 |
| 38 | 1.095226 | 0.51049 | 0.061805 | 0.040119 | 0.012174 |
| 40 | 1.057719 | 0.441661 | 0.06435 | 0.047479 | 0.007692 |
| 42 | 1.223294 | 0.44305 | 0.078004 | 0.065927 | 0.004296 |
| 44 | 23.49896 | 6.936921 | 0.914042 | 0.495994 | 0.208271 |

Figure 1 shows graph of objective function for different orders of high pass digital FIR filter. Values of the objective function for different orders have been given in table 2. Objective function decreases as order of the filter increases.



Figure 1: Objective function for different orders of high pass digital FIR filter

Coefficients of digital FIR high pass filter

HPPO algorithm has been executed for filter order 38 by tuning its parameter. Obtained filter coefficients are given below:-

Table 3: Filter coefficients of high pass digital FIR filter for order 38

| h(n) | Filter coefficients |
|---------------|---------------------|
| h(0) = h(38) | -0.002330 |
| h(1) = h(37) | 0.004511 |
| h(2) = h(36) | -0.003861 |
| h(3) = h(35) | -0.000804 |
| h(4) = h(34) | 0.007360 |
| h(5) = h(33) | -0.011302 |
| h(6) = h(32) | 0.008372 |
| h(7) = h(31) | 0.001712 |
| h(8) = h(30) | -0.014503 |
| h(9) = h(29) | 0.022013 |
| h(10) = h(28) | -0.016980 |
| h(11) = h(27) | -0.002269 |
| h(12) = h(26) | 0.028480 |
| h(13) = h(25) | -0.046427 |
| h(14) = h(24) | 0.039185 |
| h(15) = h(23) | 0.002933 |
| h(16) = h(22) | -0.074909 |
| h(17) = h(21) | 0.156907 |
| h(18) = h(20) | -0.221812 |
| h(19) | 0.246479 |

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Magnitude and Phase response

Magnitude and phase response of high pass FIR filter of 38 order is obtained using MATLAB. Frequency response is obtained from 39 filter coefficients and magnitude versus normalized frequency graph is drawn to analyse attenuation and amplification values for different frequencies. It also determines the behaviour of filter in pass band and stop band. Fig.2 represents magnitude response versus normalized frequency. Magnitude increases above 0.7π . Fig.3 shows graph of magnitude response in decibels (dB) with normalized frequency.

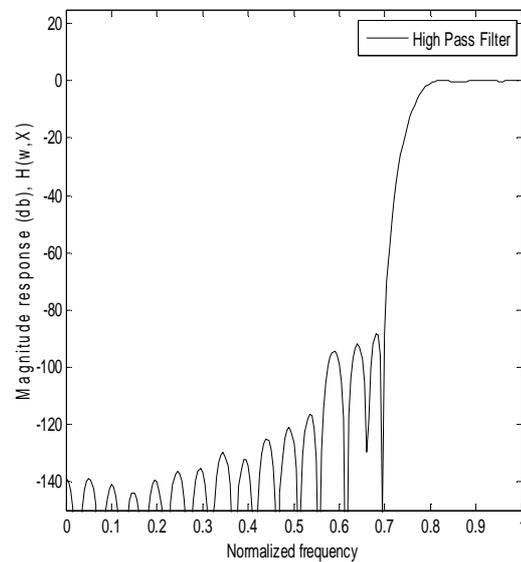
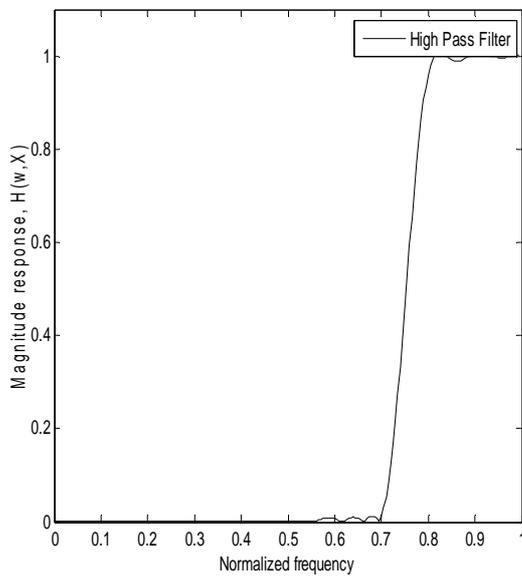


Figure 2: Magnitude response of high pass digital FIRfilter for order 38 for order 38

order

Fig.4 shows graph of phase response with normalized frequency. High pass FIR filter has linear phase above 0.7π rad/sample

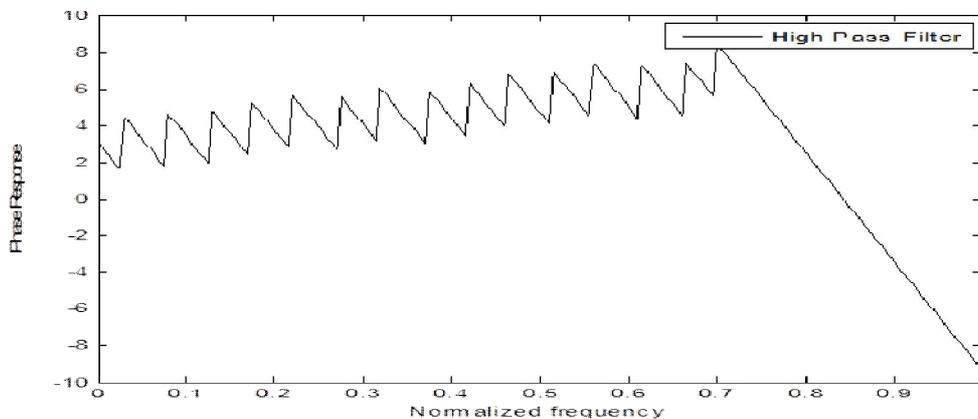


Figure 3: Phase response of high pass digital FIRfilter for order 38

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Table 4 shows maximum value ,minimum value, average value of objective function of high pass digital FIR filter for order 38. Calculated standard deviation of high pass digital FIR filter is 0.01469. Standard deviation is less than 1 which confirms the robustness of the filter.

Table 4: Maximum, Minimum, Average value of objective function and Standard Deviation of digital FIR high pass filter for order 38

| Filter type | Minimum value | Maximum value | Average value | Standard deviation |
|-------------|---------------|---------------|---------------|--------------------|
| High pass | 1.095226 | 1.14356 | 1.10559 | 0.01469 |

VI. CONCLUSION

HPPO method used to design high pass digital FIR filter achieves effective trade-off between exploration and exploitation. Higher order digital FIR filter has been designed using HPPO algorithm. High pass digital FIR filter designed using HPPO outperforms HDE in the solution quality and convergence speed. On the basis of results it is seen that HPPO has minimum value of objective function for 38 order filter. Simulation results prove that HPPO has minimum value of magnitude error and stop band ripple as compared to HDE for filter order 38. Calculated Standard deviation is 0.01469 which confirms the robustness of the designed digital FIR high pass filter. Thus the proposed algorithm is better and can be extended to the design of low pass, band pass and band stop filters.

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