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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 prey 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-

\[ y(n) = \sum_{k=0}^{M-1} b_k x(n-k) \]  

(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-

\[ H(z) = \sum_{k=0}^{M-1} b_k z^{-k} \]  

(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

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

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

Ideal magnitude response is given below:

$H_d(\omega_i)$ 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

\[ \delta_p(x) = \max \{ |H(\omega_i, x)| \} - \min \{ |H(\omega_i, x)| \} \]  

\[ \delta_s(x) = \max \{ |H(\omega_i, x)| \} \]  

All objective functions for optimization are:

\[ f_1(x) = \text{Minimize } e_1(x) \]  

\[ f_2(x) = \text{Minimize } e_2(x) \]  

\[ f_3(x) = \text{Minimize } \delta_p(x) \]  

\[ f_4(x) = \text{Minimize } \delta_s(x) \]  

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

\[ \text{Minimize } f(x) = \sum_{j=1}^{4} \omega_j f_j(x) \]  

where $\omega_j$ 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 $x_{i,k}^0$ and $x_{pi}^0$ respectively.

\[ x_{i,k}^0 = x_{i,min} + R_{ik}^1 \left( x_{i,max} - x_{i,min} \right) (i = 1,2,...,S; k = 1,2,...,N_p) \]  

\[ x_{pi}^0 = x_{i,min} + R_{i2}^2 \left( x_{i,max} - x_{i,min} \right) (i = 1,2,...,S) \]
where $x_{i\text{min}}$ and $x_{i\text{max}}$ are representing the lower and upper limit of ith decision variables; $R_{i1}$ and $R_{i2}$ are uniform random numbers having value between 0 and 1.

Prey and predator velocities are given below:-

\begin{align*}
V_{i1}^{0} & = V_{i1}^{\text{min}} + R_{i1}^{1}(V_{i1}^{\text{max}} - V_{i1}^{\text{min}}) (i = 1,2 \ldots S; k = 1,2 \ldots N_{p}) \\
V_{i2}^{0} & = V_{i2}^{\text{min}} + R_{i2}^{1}(V_{i2}^{\text{max}} - V_{i2}^{\text{min}}) (i = 1,2 \ldots S)
\end{align*}

Where minimum and maximum prey velocities are

\begin{align*}
V_{i1}^{\text{min}} & = \alpha(x_{i1}^{\text{max}} - x_{i1}^{\text{min}}) (i = 1,2 \ldots S) \\
V_{i2}^{\text{max}} & = \alpha(x_{i2}^{\text{max}} - x_{i2}^{\text{min}}) (i = 1,2 \ldots S)
\end{align*}

By varying value of $\alpha$ (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:

\begin{align*}
V_{p1}^{t+1} & = C_{4}(GP_{i}^{\text{best}} - P_{p1}^{t}) (i = 1,2 \ldots S) \\
x_{p1}^{t+1} & = x_{p1}^{t} + V_{p1}^{t+1} (i = 1,2 \ldots S)
\end{align*}

where, $GP_{i}^{\text{best}}$ is best global prey position of ith variable; $C_{4}$ is random number ranging from 0 to upper limits; $x_{p1}^{t}$ is element of position of predator; $V_{p1}^{t}$ is velocity.

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

\begin{align*}
V_{i1}^{t+1} & = wV_{i1}^{t} + C_{1}R_{1}(x_{i1}^{\text{best}} - x_{ik}^{t}) + C_{2}R_{2}(G_{i}x_{i1}^{\text{best}} - x_{ik}^{t}) ; P_{f} \leq P_{f}^{\text{max}} \\
x_{i1}^{t+1} & = x_{i1}^{t} + V_{i1}^{t+1}
\end{align*}

\begin{align*}
V_{i2}^{t+1} & = wV_{i2}^{t} + C_{1}R_{1}(x_{i2}^{\text{best}} - x_{ik}^{t}) + C_{2}R_{2}(G_{i}x_{i2}^{\text{best}} - x_{ik}^{t}) + C_{3}\alpha(e^{-b_{e}^{t}}); P_{f} > P_{f}^{\text{max}} \\
x_{i2}^{t+1} & = x_{i2}^{t} + V_{i2}^{t+1}
\end{align*}

where, $C_{1}, C_{2}$ is acceleration constant, $w$ is weight of inertia, $R_{1}, R_{2}$ is random number having value in range [0,1], $x_{i1}^{\text{best}}$ is local position of ith 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:

\begin{equation}
e_{k} = \sqrt{\sum_{i=1}^{S}(x_{ik} - x_{p1})^{2}}
\end{equation}

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

\begin{equation}
w = [w_{\text{max}} - (w_{\text{max}} - w_{\text{min}})(\frac{t}{t_{\text{max}}})]
\end{equation}

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

\begin{equation}
C_{f} = \begin{cases} 
(2 - \sigma - \sqrt{\sigma^{2} - 4\sigma}) & \text{if } \sigma \geq 4 \\
1 & \text{if } \sigma < 4
\end{cases}
\end{equation}

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.

\begin{align*}
V_{ik}^{t} & = R_{3}V_{ik}^{\text{max}} ; \text{if } V_{ik}^{t} < V_{ik}^{\text{min}} \\
V_{ik}^{t} & = R_{3}V_{ik}^{\text{min}} ; \text{if } V_{ik}^{t} > V_{ik}^{\text{max}} \\
V_{ik}^{t} & = V_{ik}^{t} \quad \text{; no violation of limit}
\end{align*}

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].

\[ x^{j+L_j}_i = x^{j\text{min}}_i + x^{j\text{max}}_i - x^j_i \]

\((j = 1, 2, \ldots; i=1, 2, \ldots, L)\)

where \(x^{j\text{min}}_i\) and \(x^{j\text{max}}_i\) 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:

\[ x^i_1 = x^i_1 \pm \Delta_i u^j_i \]

\((i=1, 2, \ldots, S; j=1, 2, \ldots, S)\)

where \(S\) denotes number of variables.

The objective function denoted by \(A(x^i_1)\) is calculated as follows:

\[ x^i_1 = \begin{cases} x^i_1 + \Delta_i u^j_i & A(x^i_1 + \Delta_i u^j_i) \leq A(x^i_1) \\ x^i_1 - \Delta_i u^j_i & A(x^i_1 - \Delta_i u^j_i) \leq A(x^i_1) \\ x^i_1 & \text{otherwise} \end{cases} \]

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 \(\Delta_i\) and \(x^i_1\) and then compute \(f(x^i_1)\)
2. Initialize iteration counter, \(IT=0\) and then increment it to \(IT+1\).
3. IF \(IP > IP^{\text{max}}\) GO TO 9
4. Initialize filter coefficient counter \(j=0\) and then increment it to \(j+1\).
5. Find \(u^j_i\) using Eq.24 and evaluate Performance Function, \(A(x^i_1 + \Delta_i u^j_i)\) and \(A(x^i_1 - \Delta_i u^j_i)\)
6. Find \(x^i_1\) using Eq.25 and evaluate \(A(x^i_1)\)
7. IF \((j \leq S)\), then increment \(j=j+1\) and repeat step 5 and 6.
8. IF \(A(x^i_1) < A(x^i_1)\) 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 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. Therefore HPPO method is used for further tuning of parameters like \(C_1\), \(C_2\) and IPOP.

<table>
<thead>
<tr>
<th>Order of the filter</th>
<th>objective function</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>20</td>
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<td>22</td>
<td>4.429965</td>
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<tr>
<td>24</td>
<td>4.17736</td>
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<tr>
<td>26</td>
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<td>28</td>
<td>2.669924</td>
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<tr>
<td>30</td>
<td>2.150152</td>
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<tr>
<td>32</td>
<td>2.04764</td>
</tr>
<tr>
<td>34</td>
<td>1.847153</td>
</tr>
<tr>
<td>36</td>
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<td>38</td>
<td>1.09574</td>
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<tr>
<td>40</td>
<td>1.119972</td>
</tr>
<tr>
<td>42</td>
<td>1.224103</td>
</tr>
<tr>
<td>44</td>
<td>1.38808</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Filter Order</th>
<th>Objective Function</th>
<th>Magnitude Error1</th>
<th>Magnitude Error2</th>
<th>Pass-band Performance</th>
<th>Stop-band Performance</th>
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</table>

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.

![Graph showing population size vs objective function for filter order 38](image)

**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.

![Graph showing acceleration constants vs objective function for filter order 38](image)

**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.

![Graph showing magnitude and phase response](image)

**Fig. 4: Magnitude and phase response**
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 tuning 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.
REFERENCES


