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

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

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

1. Introduction

A frequency selective circuit that allows a certain band of frequency to pass while attenuating the other frequencies is called a filter. A filter is a device that removes harmful constituents in the form of noise from a signal. Filters are classified into two categories: analog filters and digital filters. Analog filters: Analog filters are the device that operates on continuous-time signals. These filters use passive components such as resistor, capacitors and op-ampilifier to realize its effectiveness in the field of noise reduction, video signal enhancement and graphic equalizer. Digital filters: In signal processing, a digital filter is a system that performs mathematical operations on a sampled, discrete-time signal to achieve the desired features with the help of specially designed digital signal processor chip. It is characterized by the representation of discrete time, discrete frequency or other discrete domain signals by a sequence of numbers or symbols and the processing of these signals. To perform the processing digitally, there is a need for an interface between the digital processor and the analog signal. A digital signal processor is an integrated circuit designed for high-speed data manipulations and is used in audio communication, image manipulation and other data acquisition and data control applications. A filter is frequency discriminating circuit that allows the certain range of frequencies to pass through, attenuating others. Filters are used in applications like radar, noise reduction, audio processing, video processing etc. Digital filters are two types: Finite impulse response (FIR) and Infinite impulse response (IIR) filter. A finite impulse response (FIR) is a type of digital filter whose impulse response is of finite duration. Whereas an IIR filter has infinite impulse response exists for zero to infinity. FIR filter has a number of advantages: High stability, linear phase response, low quantization noise, simple implementation [7]. There are many traditional techniques used for the design of digital FIR filters, like window based methods, frequency sampling method and least mean square error etc. There are variety of windows (Blackman, Hamming, Rectangular, Kaiser etc.) which limits the infinite impulse response of ideal filter into finite window to design actual response [1-7]. Parks and mcclellan [1] proposed the Chebyshev approximation method that results much better than other traditional techniques, but it too has limitation of computational complexity and high pass band ripples.

GA gives better results than window method and Parks and McClellan optimization technique [8]. Steepest method of optimization can approximate any kind of frequency response for linear phase FIR filter but the transition width is to be compromised which is not acceptable. The other classical gradient based optimization methods are not suitable for FIR filter optimization[6].

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

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

2. Design Formulation of Digital Filter

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

\[ y[n] = \sum_{k=0}^{M} h[k] x[n-k] \]

\[ h[k] = \frac{r_k}{\sum_{k=0}^{M} r_k} \]

where, \( y[n] \) is the output, \( x[n] \) is the input and \( h[k] \) is the filter coefficients. The design formulation of FIR digital filter is as follows:

- **Design of FIR Filter**: The design of FIR filter is based on the approximation of the ideal filter response. The ideal filter response is a rectangular window in the frequency domain.
- **Window Function**: The window function is used to approximate the ideal filter response. The window function is a finite-length sequence that is used to weight the impulse response of the filter.
- **Filter Order**: The filter order determines the number of coefficients in the filter. The higher the filter order, the more coefficients are used and the better the approximation of the ideal filter response.

**Conclusion**: The design of the FIR filter is an important aspect of digital signal processing. The choice of window function and filter order can significantly affect the performance of the filter. The design formulation of the FIR filter is based on the approximation of the ideal filter response. The window function is used to approximate the ideal filter response. The filter order determines the number of coefficients in the filter. The higher the filter order, the more coefficients are used and the better the approximation of the ideal filter response.
\[ y(n) = \sum_{k=0}^{M-1} b_k x(n - k) \]  

where \( y(n) \) is output sequence, \( x(n) \) is input sequence, \( b_k \) is coefficient, \( M \) is the order of filter.

The transfer function of FIR filter is given as:

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

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

\[ h(n) = \{b_n, 0 \leq n \leq M - 1, 0, \text{otherwise} \]  

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

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

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

\[ h(n) = h(N-1-n) \text{ for Symmetric} \]  

\[ h(n) = h(N-1-n) \text{ for Asymmetric} \]

For such a system the number of multiplication is reduced from \( N \) to \( N/2 \) for \( N \) even and to \( (N-1)/2 \) for odd. The FIR filter is designed by optimizing the coefficients in such a way that the approximation error function in \( L_p \)-norm for magnitude is to be kept minimal. The magnitude response is specified at \( K \) equally spaced discrete frequency points in pass-band and stop band.

\[ e_1(x) = \sum_{i=0}^{M-1} |H_d(\omega_i) - |H(w_i, x)| \]  

\[ e_2(x) = \sum_{i=0}^{M-1} |H_d(\omega_i) - |H(w_i, x)| \]

Ideal magnitude response of FIR filter is given as:

\[ H_d(w_i) = \begin{cases} 1 & \text{for } w_i \text{ in passband} \\ 0 & \text{for } w_i \text{ in stopband} \end{cases} \]

The ripple magnitudes of pass-band and stop-band are to be minimized which are given by \( \delta_1(x) \) and \( \delta_2(x) \) respectively. Ripple magnitude are:

\[ \delta_1(x) = \max \{ |H_d(w_i, x)| - |H(w_i, x)| \} \]  

\[ \delta_2(x) = \max \{ |H_d(w_i, x)| - |H(w_i, x)| \} \]

Four objective functions for optimization are:

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

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

\[ \text{Minimize } f_3(x) = \delta_1(p) \]  

\[ \text{Minimize } f_4(x) = \delta_2(p) \]

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

\[ \text{Minimize } f(x) = w_1 f_1(x) + w_2 f_2(x) + w_3 f_3(x) + w_4 f_4(x) \]

where \( w_1, w_2, w_3 \) and \( w_4 \) are weights.

3. Predator Prey Optimization Technique Employed

In the conventional PSO algorithm, the swarm would come together at a time and then it must be difficult for them to escape from the accumulator point. After that, the algorithm would lose its global search ability. For overcoming this deficiency of PSO, a predator-prey model has been developed by silva[4]. The motivation has mainly introduced diversity in the swarm position at any moment during the run of the algorithm, which does not depend on the level of convergence already achieved. Higashitani[5] have developed the predator prey optimization (PPO) method and applied on several benchmark problems and has compared with PSO method. PPO performed significantly better than the standard PSO while implanted on benchmark multimodal functions.

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

\[ V_{P_i}^{t+1} = C_4 (G Pbest_i^t + p^S) (i = 1, 2, ..., S) \]  

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

\[ X_{P_i}^{t+1} = X_{P_i}^t + V_{P_i}^{t+1} (i = 1, 2, ..., S) \]

where \( G P best_i^t \) is global best prey position of \( i^{th} \) variable, \( C_4 \) is random number lies between 0 & upper limits.

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

\[ V_{I_i}^{t+1} = \begin{cases} \omega v_i^t + C_1 R_1 (x_{best_i}^t - x_i^t) + C_2 R_2 (x_{G best_i}^t + x_i^t) : p_i \leq p_{i_{max}} \\ \omega v_i^t + C_1 R_1 (x_{best_i}^t - x_i^t) + C_2 R_2 (x_{G best_i}^t + x_i^t) + C_3 a e^{-a w} : p_i > p_{i_{max}} \end{cases} (i = 1, 2, ..., S; K = 1, 2, ..., N_p) \]

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

\[ x_{I_i}^{t+1} = x_{I_i}^t + C_3 v_{I_i}^{t+1} (i = 1, 2, ..., S; K = 1, 2, ..., N_p) \]

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

3.1 Algorithm

1. Input data viz. maximum allowed movements, swarm size, maximum and minimum limit of velocity, maximum probability bear (\( P_{i_{max}} \)) etc.
2. Randomly initialize the prey and predator positions being decision variables.
3. Randomly initialize the prey and predator velocities.
4. Apply opposition based strategy.
5. Compute augmented objective function.
6. Select \( N_p \) best preys from total \( 2N_p \).
7. Assign all prey positions as their local best position.
9. Update predator velocity and position.
10. Randomly generate the probability bear within \((0,1)\).
11. IF (probability bear > maximum probability bear) THEN
    Update prey velocity and position with predator affect ELSE
    Update prey velocity and position without predator affect
    ENDIF.
12. Compute augmented objective function for all prey population.
15. Check stopping criteria, if not met, step 9.
16. Stop.

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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>100</td>
</tr>
<tr>
<td>Iteration cycle</td>
<td>200</td>
</tr>
<tr>
<td>$C_1, C_2$</td>
<td>2.0, 2.0</td>
</tr>
<tr>
<td>$w_{min}$</td>
<td>0.1</td>
</tr>
<tr>
<td>$w_{max}$</td>
<td>0.4</td>
</tr>
<tr>
<td>$W_3, W_4$</td>
<td>11.0, 7.0</td>
</tr>
</tbody>
</table>

Table 2: Design condition for high pass FIR digital filter

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

4. Simulation Results

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

Table 3: Objective Functions values at different filter orders

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

Hence the filter order 28 gives the minimum value of objective function. So filter order 28 has been preferred for the design of digital high pass FIR filter. Now variation in filter order with variation in objective function as shown in fig 1.
The values of acceleration constants ($C_1$, $C_2$) are varied from 1 to 4. The objective function is varying from the values 1 to 2 of acceleration constants. There is a gradual increase in the value of objective function for the values of $C_1$, $C_2$ between 2 to 4. The value of objective function is minimum when $C_1$, $C_2$ is having value 2. So this value of $C_1$ and $C_2$ is selected.

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

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

Fig 7 shows the graph of variation in phase response with variation in normalized frequency.
Table 6: Max, Min and Avg value of objective function along with standard deviation at filter order 28

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Max objective function</th>
<th>Min objective function</th>
<th>Average value</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.614643</td>
<td>2.558787</td>
<td>2.586715</td>
<td>0.027928</td>
</tr>
</tbody>
</table>

5. Conclusion

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

References


