DESIGN OF LINEAR PHASE FIR FILTER USING OPTIMIZATION

Harmandeep Kaur[1], Dr. Manjit Verma[2]
[1]Research Scholar, [2]Assistant Professor
School of Engineering (Electronics and Communication Engineering)
RIMT University, Mandi Gobindgarh, Punjab, India

Abstract: In this paper, a new optimization technique called seeker optimization is applied to design an optimal Finite Impulse Response (FIR) filter. This optimization algorithm will determine the optimal coefficients of the FIR band pass filter to meet the required magnitude response of the filters. An optimization function taken in this is based upon the error formed in the filter to be designed. Seeker optimization is based on the behaviour of human beings to solve any problem and the individuals are known as seekers. Simulative results of the proposed seeker technique have been compared to the well-known optimization techniques known as Particle Swarm optimization (PSO) and Bat optimization. Seeker based results shows its superiority for designing the optimal FIR filter in comparison to those acquired by PSO but shows quite similar results as obtained by Bat.

Index Terms **- FIR filter, PSO, Bat algorithm, Seeker**

I. INTRODUCTION

In this burgeoning every, every technological field is gaining interest of the researchers as with case of digital filter designing. Filter designing involves the selection of useful information by rejecting the unwanted portion of data. With the advancements in information processing, digital filters are used in almost every field in comparison to analog filters. Filters are classified on the basis of different criteria's- type of the input signal, frequency characteristics, duration of impulse response. On the basis of input signal these are termed as analog and digital filters; and on the basis of frequency characteristics, there are four types of filters namely low pass, high pass, band pass and band stop filters. Depending upon the impulse response duration, these are categorised as finite impulse response (FIR) and infinite impulse response filters. Each filter has its own merits and demerits. As the name indicates FIR filter is defined as the filter whose impulse response is of finite duration as it settles down to zero in finite time whereas IIR filter is a filter whose impulse response is of infinite duration and never settles down to zero as it contains both poles and zeroes. FIR filter is efficient in terms of linearity and stability but it requires more memory and more number of coefficients as compared to IIR filter which has the advantage of less memory and requires less number of coefficients to filter the signal. FIR filter is also known as all-zero filter. This paper deals with the designing of the FIR filters and the parameters considered for the designing are: cut-off frequencies, pass band and stop band ripples, attenuation, filter order and filter coefficients. [*1*][*2*].

Filter designing is a process in which filter coefficients and filter order are determined in accordance with the given set of specification and filter parameters. There are different methods adopted by the researchers to design FIR filters for example window method [*1*][*3*][*4*][*5*], frequency sampling [*1*][*4*][*5*][*6*], and optimal design or weighted least squares [*1*][*4*][*5*]. Traditionally window method was the most commonly used method for its designing. However, due to various limitations of the window method, such as in this method, a designer does not have the flexibility to set all the filter parameters. Nowadays, optimization techniques are much popular among technicians to design an optimum FIR filter with the given design specifications. An optimization is a process in which the best variables are selected from a particular set of variables by applying certain constraints too. Previously, genetic algorithms (GA) were used for the implementation of FIR filters. Afterwards, swarm optimization such as particle swarm optimization came into effect and gained much interest in recent years for the digital filter designing. Different techniques such as Parks McClellan algorithm [*7*], Genetic Algorithm (GA) [*8*], Particle Swarm Optimization (PSO) [*8*][*9*][*10*], Differential Evolution (DE) [*10*][*11*][*12*][*13*], Artificial Bee Colony Optimization (ABC) [*14*], Teaching Learning Based Optimization (TLBO) [*15*][*16*], Cat Swarm optimization [*16*], Cuckoo Search algorithm (CS) [*17*] and Bat Algorithm[*18*]are being used in this era for the design of digital filters. Severino et al. designed a low pass FIR filter using PSO and Bat Algorithm. Based on the simulation results filter design using Bat algorithm is better than using PSO and PM [*19*].

Dai et al. proposed a new algorithm called seeker optimization algorithm for real-parameter optimization [*20*]. After that seeker optimization technique has been used in various applications such as optimal reactive power dispatch problem [*21*], IIR filter designing [*22*]. However, for filter design very less application is found by the literature. In this paper, seeker optimization algorithm has been used to design the FIR band pass filter. The simulation results based on this design is presented here and compared to those with PSO and Bat optimization algorithm.

The paper is arranged in the following manner. Section 1 presents the introduction. Section 2 describes the FIR filter design problem. In Section 3 optimization techniques are discussed. Section 4 describes the use of optimization technique for the designing of FIR filter. Section 5 presents the simulation results obtained by the technique. Finally, Section 6 concludes the paper.

II. FIR FILTER DESIGN PROCEDURE

Design procedure of FIR filter requires, filter designer to provide required filter design specifications such as filter order, cut-off frequencies etc. and in accordance with those filter is designed whose frequency response best matches with the ideal frequency response**[*1*][*2*][*4*]**.The frequency response of filter is given as:

$$\mathbf{H_d(e^{iw}) = \sum_{n=0}^{N} h(n)e^{-iwn}} \quad (3)$$

$\mathbf{n = 0, 1, \ldots\ldots\ldots\ldots\ldots N}$

Where h (n) is the impulse response of filter. N is the order of filter with N+1 number of coefficients. The coefficients of filters are symmetrical due to which the dimension of problem is halved. Therefore (N/2 +1) number of coefficients need to be actually optimized.

The magnitude response of the ideal filter for LP, HP, BP and BS filters is given by (4), (5), (6) and (7) respectively.

$$H_i(e^{iw}) = \begin{cases} 1 & for\ 0 \le w \le w_c \\ 0 & otherwise \end{cases} \quad (4)$$

$$H_i(e^{iw}) = \begin{cases} 0 & for\ 0 \le w \le w_c \\ 1 & otherwise \end{cases} \quad (5)$$

$$H_i(e^{iw}) = \begin{cases} 1 & for w_{c1} \le w \le w_{c2} \\ 0 & otherwise \end{cases} \quad (6)$$

$$H_i(e^{iw}) = \begin{cases} 0 & for w_{c1} \le w \le w_{c2} \\ 1 & otherwise \end{cases} \quad (7)$$

wherew_c is the cut off frequency of LP and HP filters; ω_{c1} and ω_{c2} are the lower and upper pass band/ stop band edge frequencies of BP and BS filters.

$\delta_p$andδ_s are the ripple magnitudes of pass-band and stop-band respectively

$$\delta_p = \max_{wi}|H(w_i, x)| - \min_{wi}|H(w_i, x)| \qquad \text{For } w_i € \text{pass band} \quad (8)$$

$$\delta_s = \max_{wi}|H(w_i, x)| \quad (9)$$

For wi € pass band

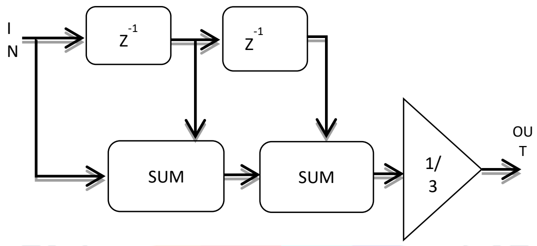

Figure 1: FIR filter

III. OPTIMIZATION TECHNIQUES USED

A. Particle Swarm Optimization

PSO is a population based optimization technique proposed by Kennedy and Eberhart[*23*] in 1995. It is a swarm based optimization algorithm which depends upon the bird flocking, fish schooling etc. it is a very popular technique in almost every field of engineering to solve optimization problems particularly in filter designing as it do not get trapped in local optimum solution like previous optimization techniques. It emerges from the natural process of the swarm of birds and uses their search procedure to reach at the target. In this algorithm, each individual known as particle keeps a record of its own best position and its best position in correspondence to the whole group and these positions are termed as personal best (pbest) and global best (gbest) respectively. They share this information with the whole swarm and update their positions in accordance with these best ones [*24*]. The variations in their best positions are done using the following information:

1. The distance between its current position and pbest.
2. The distance between its current position and gbest.

Using an iterative process, the positions of the particles are updated from time to time till the maximum number of iteration is reached and best position is selected by the algorithm automatically.

The velocity of the particle is updated according to the following equation:

$$V_i^{(k+1)} = w * V_i^k + C_1 * rand_1 * \left(pbest_i^k - S_i^k\right) + C_2 * rand_2 * (gbest^k - S_i^k) \quad (10)$$

where V_i^k is the velocity of ith particle vector at kth iteration; w is the weighting function; C1 and C2 are the positive weighting factors; $rand_1$ and $rand_2$ are the random numbers between 0 and 1; S_i^k is the current position of ith particle vector h (n) at kth iteration; $pbest_i^k$ is the personal best of the ith particle at the kth iteration; $gbest^k$ is the group best of the group at the kth iteration.

The position of the particle is updated according to the following equations:

$$X_i^{(k+1)} = X_i^k + V_i^{(k+1)} \quad (11)$$

This technique is also suitable for non-differential objective functions like digital filters. For designing an FIR filters, error functions is considered to be an objective function which is minimized by an iterative process and provides the optimum values of filter coefficients h(n).

B. Bat optimization

Bat algorithm proposed by Yang [*18*] is inspired form the behaviours of batsfor searching of food. It is almost similar to that of PSO as it updates the positions of its particles as per the velocity and position equations. It uses the echolocation property of bats to sense the distance between the object and target. However in contrast to PSO, it also takes the advantage of frequency equation which directly influences the frequency equation. Bats can fly randomly with a particular velocity v_i at position xi starting with a minimum frequency f_{min}, a varying wavelength λ and loudness A_o to find the target. Wavelength of the emitted pulses can automatically be adjusted and also the rate of pulse emission r € [0, 1] depending on the proximity of the target. The loudness varies from higher value (A_o) to smaller constant value Amin on finding the prey.

Bat Motion and variations of loudness and pulse rates

Each bat has its initialized velocity v_i, position x_i and pulse frequency f_i in a solution space. The new velocity position v_i^t and position x_i^t of the bats are updated at every time step t in accordance with the velocity and position equations as follows:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (12)$$

$$v_i^t = v_i^{t-1} + (x_i^{t-1} - x^*) f_I \quad (13)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (14)$$

$$x_{new} = x_{old} + \varepsilon A^t \quad (15)$$

Pulse rate and the loudness values are varied according to the following equations:

$$A_i^{t+1} = \alpha A_i^t \quad (16)$$

$$r_i^{t+1} = r_i^0[1 - exp(-\gamma t)] \quad (17)$$

C. Seeker optimization

SOA imitates the behaviour of humans to solve the optimization problems. It works on the basis of human searching to reach at the desired optimum solution. Each individual in this are known as seekers. Each seeker has its own centre position, search radius, trust degree and search direction and in accordance with these parameters, each seeker updates its position [20][21][22]. Each seeker is initialised with a random value and afterwards their positions are changed as per the following equation:

$$X_{id}(t+1) = X_{id}(t) + \alpha_{id}(t)\beta_{id}(t) \quad (18)$$

Where $\alpha_{id}(t)$ and $\beta_{id}(t)$ are the step length and search direction of the i^{th} seeker and d^{th} dimension.

β_{id} = 1 indicates that the i^{th} seeker moves in the positive direction on the dimension whereas β_{id} = -1 indicates its movement in negative direction and β_{id} = 0 shows that no movement of the i^{th} seeker. Step length and search direction are updated at each iteration depending upon the following factors.

Search direction

The variation in the actual search direction depends upon the four parameters: an egotistic term (equation 19), two altruistic terms (equations 20 and 21) and a pro-activeness term (equation 22).

$$\beta_{i,ego}(t) = sign\ (P_i(t) - X_i(t)) \quad (19)$$

where P_i represents the best experience of i^{th} seeker and sign (.) represents signum function.

$$\beta_{i,alt1}(t) = sign\ (P_g(t) - X_i(t)) \quad (20)$$

where P_g represents the best experience of all seekers in the corresponding neighbourhood.

$$\beta_{i,alt2}(t) = sign\ (l_g(t) - X_i(t)) \quad (21)$$

where l_g represents the current best of all seekers in the corresponding neighbourhood.

$$\beta_{i,pro}(t) = sign\ (X_i(t_1) - X_i(t_2)) \quad (22)$$

IV. FILTER DESIGN USING OPTIMIZATION

The main objective of this study is to design an optimal digital FIR filter with better design considerations with the use of Seeker optimization and the results are compared with PSO and bat optimization designed filters. Different parameters are considered during the optimal filter designing are pass band and stop band frequencies (w_p and w_s), pass band and stop band ripples (δ_p and δ_s) and short transition width. Different design conditions are used in different literatures by fixing some parameters and optimizing the others. In [17], filter order (N), pass band and stop band ripples are fixed and others are optimized. In Parks and McClellan (PM) algorithm [7], filter order (N), pass band and stop band frequencies (w_p and w_s), and the ratio of δ_p/δ_s is fixed.

Error function is the major parameter to be considered in all optimization algorithms. For the same problem to be designed, different error functions will generate different results. It depends upon the designer to select particular error function in accordance with the demands of the problem. The Parks McClellan algorithm uses the weighted approximate error for FIR filter design [7] as presented in (23).

$$\mathbf{E(w) = G(w)[H_d(w_k) - H_i(w_k)]} \quad (23)$$

where $\mathbf{H_d(w_k)}$ is the frequency response of desired filter and $\mathbf{H_i(w_k)}$ is the frequency response of ideal filter. G (w) represents the weighting function that gives the different weights to approximate error in different frequency bands. The major disadvantage of PM algorithm is the fixed ratio of $\boldsymbol{\delta_p/\delta_s}$. Different types of error functions have been used in different literatures as given in [12][13][25]. The Lp norm approximation error for the magnitude response is defined as:

$$\mathbf{Error} = \left\{\sum_{i=0}^{k}\left[\left||\mathbf{H_d(w_k)}| - |\mathbf{H_i(w_k)}|\right|\right]^{\mathbf{p}}\right\}^{\frac{1}{\mathbf{p}}} \quad (24)$$

where $H_i(w_i)$, is the magnitude response of ideal FIR filter and $H_d(w_{i,x})$, is the magnitude response of the designed FIR filter. When P=1 and P=2, the error function becomes as follows:

$$Error = max\left\{\sum_{i=0}^{k}\left[\left|H_d(w_k) - |H_i(w_k)|\right|\right]\right\} \quad (25)$$

$$Error = \left\{\sum_{i=0}^{k}\left[\left||H_I(w_k)| - |H_D(w_k)|\right|\right]^2\right\}^{\frac{1}{2}} \quad (26)$$

By individually specifying the required values for δ_p and δ_s, flexibility in the error function can further be improved by specifying the error function as presented in [8].

$$J_1 = \max_{w \le w_p}\left(|E(w)| - \delta_p\right) + \max_{w \ge w_s}\left(|E(w)| - \delta_s\right) \quad (27)$$

For designing a filter using any optimization problem, these error functions are considered as an objective function of the problem and are minimised using optimization. A minimum value of the error function is taken as the final value and in correspondence to that, a new set of coefficients are formed for the filter. In this paper, the error function given in (equation 27) is taken due to its obvious advantages as the values of the pass band and stop ripples can be individually specified.

V. NUMERICAL ANALYSIS AND RESULTS

In this section, the simulative results are presented for the designing of FIR band pass filter. The simulations are performed in the MATLAB simulative environment. Filter order is taken as 40 after comparing the different orders for the same problem. The value of sampling frequency taken is f_s = 1 Hz and number of frequency samples are 512. The number of iterations is taken as 100.The specification parameters of the filter to be designed using optimization techniques are taken as: pass band ripple (δp) = 0.1, stop band ripple (δs) = 0.01. For band pass upper and lower cut off frequencies (normalised) are 0.3 and 0.7.

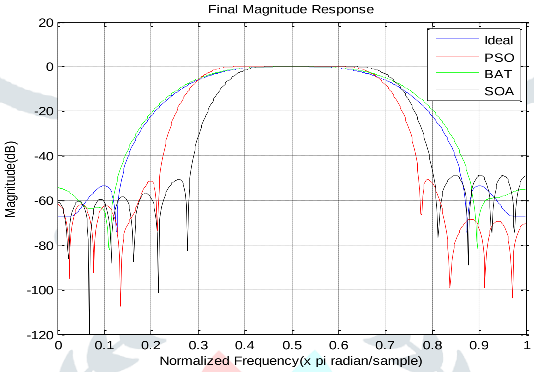

Figure 2: dB plot for the FIR band pass filter

Figure 2 shows the magnitude response for FIR band pass filter and figure 3 represents the normalised magnitude response. Figure 4 shows the pass band ripples obtained during the designing of FIR filter and figure 5 shows the stop band ripples for FIR filter. Figure 6 gives the comparison of the convergence profile of all the three optimization techniques used i.e. the value of fitness functions which is 8.467 for seeker, 51.81 for Bat and 80.30 for PSO. Hence seeker optimization shows its superiority for designing the filter in comparison to bat and PSO as the fitness function obtained by seeker is minimum.

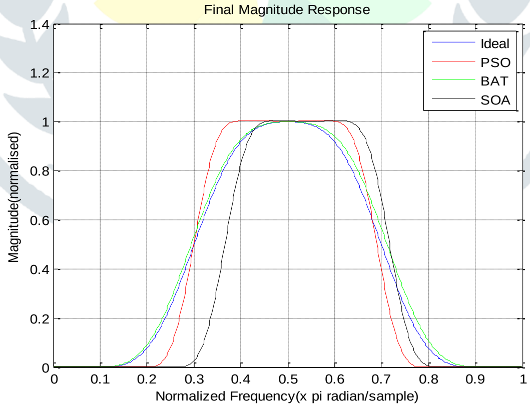

Figure 3: Normalised plot for the FIR band pass filter

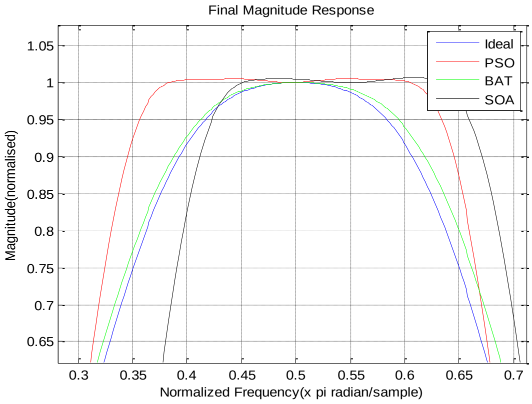

Figure 4: Pass band ripple for the FIR band pass filter

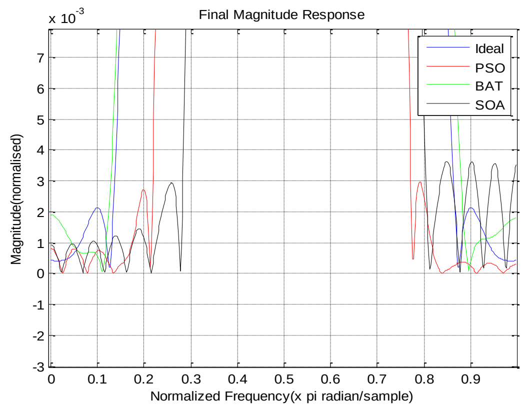

Figure 5: Stop band ripple for the FIR band pass filter

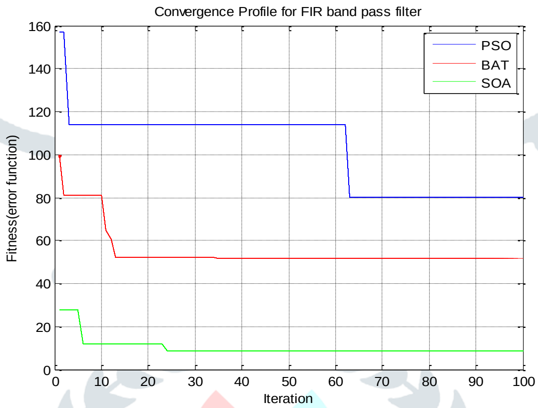

Figure 6: Comparison of the convergence profile for Seeker, Bat and PSO

VI. CONCLUSION

In this paper, three optimization algorithms are compared for designing of FIR filter. The results are compared for FIR band pass filter and seeker optimization shows the minimum value of fitness function. This paper indicates that the seeker optimization can be used for filter designing very efficiently. Moreover PSO and Bat techniques show almost similar results and indicates that these can also be used for filter design. By analysing the simulation results, the design based on these techniques are feasible. The magnitude responses obtained in relative to the ideal filter are very appropriate. Moreover pass band ripples and stop band ripples are also very less. The fitness function obtained by seeker comes out to be minimum i.e. is 8.467.

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