NATURE-INSPIRED OPTIMIZATION TECHNIQUE FOR THE DESIGNING OF BAND-PASS DIGITAL FIR FILTER

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ABSTRACT

This paper showcases designing of optimal digital FIR band-pass filter using Bio-inspired heuristic optimization (PSO) technique. PSO is a robust technique with inherent parallelism, which can be easily handled with non-differential objective functions, unlike conventional optimization methods. For the designing purpose, complex calculations are to be made for obtaining the filter coefficients. The magnitude and phase response are observed using MATLAB. Other statistical parameters are calculated and analysed for the better designing of FIR Band-pass filter.

Key points*— *FIR Band-pass filter, Optimization methods, PSO technique, magnitude and phase response.

I. INTRODUCTION

Signal, as we all know is the carrier of information and data which is embedded in almost every field of engineering and science, opens up a whole new division of research. Processing a signal means filtering the signal from unwanted noise and interference. DSP is an integrated circuit designed for manipulating the high speed data and finds its applications in hard disc controllers, biomedicine and many other fields [11].

Filters are frequency selective circuits that allow a certain range of frequencies to pass through, attenuating others and are used in applications like noise reduction, radars, audio processing etc. Based upon this the filters are classified into- Low-pass, High-pass, Band-pass, Band-stop filters. Filters are used for creating a perceptual audio/visual effect for entertainment and in broadcast studios. Filters serve two purposes: Signal separation which is required when signal is contaminated with noise whereas signal restoration comes handy when signal has been lost or distorted like obstacles in way of travelling light.

Filters are also segmented according to the input used- Analog filters have analog input at both input and output and are functions of continuous time signals and have infinite number of values whereas digital filters use digital processors to perform numerical calculations and work on discrete time signals. Digital filters are divided into IIR and FIR filters.

IIR filters are also coined as recursive filters and these operate on current and past input values as well as current and past output values. Impulse response of an IIR filter never reaches zero and is an infinite response. FIR filters are digital filters that have finite impulse response duration and operate only on current and past values. If a single impulse is present at input of an FIR filter and all subsequent inputs are zero, output of a FIR filter becomes zero after a finite time. It is also termed as non-recursive as present response depends only on input terms and shows no dependence on past values. FIR filters are classified into symmetric and anti-symmetric filters.

Different methods and techniques have been used in past for the designing of FIR filters like GA [2, 12], Differential Evolution [4] etc. In this the benefits of designing FIR filter with PSO technique are highlighted. This technique emphasizes its benefits and efficiency than the techniques used in the past. The Bio-inspired technique was developed by Eberhart and Kennedy [1]. It is quite simple to implement compared to other techniques. Much work has already been done in this field in order to explore the elasticity of FIR filter designed by Bio-inspired technique [6, 9, 13, 14, 16, 17, 18] and their various other types [3, 7, 8, 10].

This paper is segmented into four sections- Section II discusses the problem formulation, Section III covers the methodology, Section IV comprises of results and last Section V gives the conclusion.

2. Problem Formulation

FIR filters are also called non-recursive filters as they do not have feedback and have finite impulse response. A tapped delay line filter which is also referred to as transversal filter is used over here and comprises of three basic elements- unit delay element, multiplier and adder.

Difference equation of FIR filter is as shown below:

$$y(n) = \sum_{k=0}^{M-1} b_k \, x(n-k) \tag{1.1}$$

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

The transfer function of FIR filter is given as:

$$H(z) = \sum_{k=0}^{M-1} b_k \, z^{-k} \tag{1.2}$$

The output sequence can also be represented as convolution of unit sample response h(n) of system with its input signal:

$$y(n) = \sum_{k=0}^{M-1} h(k) \, x(n-k) \tag{1.3}$$

FIR filters have symmetric and anti- symmetric properties, which are related to their h(n) under symmetric and asymmetric conditions as described below by equations:

$$h(n) = h(N-1-n) \qquad for\ even$$

$$h(n) = -h(N-1-n) \qquad for\ odd$$

For such a system the number of multiplications is reduced from M to M/2 for M even and from M to (M-1)/2 for odd.

The FIR filter is designed by optimizing the coefficients in such a way that the approximation error function in Lp-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) – absolute error L1-norm of magnitude response

$$e_1(x) = \sum_{i=0}^{K} \left| H_d(\omega i) - |H(w_i, x)| \right| \tag{1.4}$$

Desired magnitude response:

$$Hd(\omega i) = \begin{cases} 1\ for\ \ w_i \in passband \\ 0\ for\ \ w_i \in stopband \end{cases} \tag{1.5}$$

For the design of digital FIR filters, the inclusion of stability constraints is compulsory.

δ_p and δ_s are the ripple magnitudes of pass-band and stop-band.

$$\delta_p = max_{wi}|H(w_i, x)| - min_{wi}|H(w_i, x)| \qquad \text{for } w_i \in \text{pass band} \tag{1.6}$$

$$\delta_s = max_{wi}|H(w_i, x)| \qquad \text{for } w_i \in \text{stop band} \tag{1.7}$$

Three objective functions for optimization are:

$$Minimize\ f_1(x) = e_1(x) \quad (1.8)$$

$$Minimize\ f_2(x) = \delta_p\ (x) \quad (1.9)$$

$$Minimize\ f_3(x) = \delta_s\ (x) \quad (1.10)$$

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

$$\text{Minimize}\ \ f(x) = w_1 f_1(x) + w_2 f_2(x) + w_3 f_3(x) \quad (1.11)$$

w_1, w_2 and w_3 are weights.

III. OPTIMIZATION METHODOLOGY

Optimization algorithm is a procedure which is executed repeatedly by comparing various solutions till optimal solution is found. Particle Swarm Optimization is a global optimization algorithm developed by Kennedy and Eberhart [2] in 1995. Like others it is a population based heuristic search algorithm and is initialized with a population of random solutions called particles. Particle Swarm Optimization is quite related to bird flocking, fish schooling and swarm theory.

The ideal solution is obtained by the algorithm cause of the variability of some particles in the tracing space. These particles then search in the solution space trailing the best particle with changing their positions, the flying direction and velocity are determined by the objective function.

PSO was born from the research of food hunting behaviours of birds. During their research on this they found that in the course of flight, the flocks of birds would suddenly change their course of direction, scatter and gather again. Thus when similar biological communities were also researched upon, it was found that a social information sharing mechanism existed between those biological communities. This mechanism provides an advantage for the evolution of these biological communities and also became the basis for the formation of PSO.

Every swarm of Particle Swarm Optimization is a solution in the solution space. The best position during the entire course of flight of each swarm is the best solution of that swarm. Thus the best position of the whole flock is the best solution which is searched by the flock. The former value is called pbest whereas latter one is known as gbest. The PSO concept consists of changing the velocity at each step, toward its pbest and gbest locations.

Apart from this, there is also a local version of PSO, where along with pbest, every particle keeps track of the best solution called lbest, obtained within a local topological neighbourhood of particles.

Algorithm for PSO:

1. Start population of particles having random positions and velocities on d dimension in the space.
2. Observe the desired optimization fitness function in d variables for each and every particle.
3. Compare the fitness value with the swarm particle's pbest. If the fitness function value is better than the pbest, then set pbest value equal to the current value and also the pbest location to the same as current location in d-dimensional space.
4. Compare the fitness evaluation value with the population's overall previous best. If the fitness evaluation is better than gbest then change gbest value to the current particle's array index and value.
5. Changing the velocity and position of the particle according to the equations (a) and (b) listed below:

$$v_{id}^{t+1} = w * \{ v_{id}^t + c_1 * rand() * \left(p_{id}^t - x_{id}^t\right) + c_2 * Rand() * (p_{id}^t - x_{id}^t)\} \quad (1.12)$$

$$x_{id}^{t+1} = x_{id}^t + v_{id}^{t+1} \quad (1.13)$$

Where c_1 *and* c_2 are acceleration constants which represent weighting of stochastic acceleration terms that pull each particle toward pbest and gbest positions.

rand() and Rand() are two random functions in the range [0,1]

$X_i = (x_{i1}, x_{i2}, \ldots . x_{iD})$ Represents the ith particle;

$$w = w_{max} - (w_{max} - w_{min})\,({}^{IT}/_{MAX\ IT}) \qquad (1.14)$$

Where w is the weighting function and will be updated by progressive iterations,

w_{max} is the maximum value of weighting function,

w_{min} is the minimumvalue of weighting function

IT- iterations and MAX IT- maximum iterations.

6. Till the stopping criterion is not met, go back to step 2.
7. End.

IV. SIMULATION RESULTS

Now coming onto the results section, in this FIR band-pass filter is designed using Bio-inspired algorithm technique. The algorithm has been implemented by varying the filter order as well as PSO parameters for achieving the optimum result. To start with, first of all the order of the filter has to be decided and which has been done by executing it on order 18 to order 36 and the program is carried out 100 times to achieve the best result. After analysis, satisfactory results are found to be achieved at filter order 28 with the number of coefficients being 29 in this case. The parameters used for the designing of digital FIR filter are shown in table I.

TABLE I: At filter order 28, the max-mini value of pass-band along with max-min value of pass band and max value of stop band.

Maximum value of Pass Band	1.003166
Minimum value of Pass Band	.993172
Maximum - minimum value of pass band	.009994
Maximum value of Stop Band	.021230

The coefficients obtained for designing the desired FIR Band-pass filter at order 28 have been shown in Table II.

Table II: Optimized Coefficients of FIR digital Band-pass filter with order 28

A(0)=A(28)	.010306
A(1)= A(27)	.003398
A(2)= A(26)	-.011514
A(3)= A(25)	-.000989
A(4)= A(24)	-.017455
A(5)= A(23)	-.005712
A(6)= A(22)	.052770
A(7)= A(21)	.005178

A(8)= A(20)	-.023563
A(9)= A(19)	.002959
A(10)=A(18)	-.110040
A(11)=A(17)	-.007703
A(12)=A(16)	.282059
A(13)=A(15)	.003960
A(14)	-.361733

The average and standard deviation values of filter order 28 are calculated to be:

Table III: Statistical calculations on order 28 of FIR Band-pass Filter

S. No.	Minimum value	Maximum value	Average value	Standard Deviation
1	0.981329	1.244792	1.011679	0.095284

Thus lower the value of standard deviation, a filter becomes more robust.

The graph shown in Fig 1 is drawn between filter orders and their respective objective functions obtained during the execution.

Fig 1: Order-objective function plot of FIR Band-pass Filter

During changing of filter order from 18 to 36, the value of objective function remains almost constant for 20 to 27. Minimum value of objective function is achieved at filter order 28. With further increase in filter order, the value of objective function increases rapidly from 0.981329 to 35.17637.

For FIR filter with filter order of 28, the other parameters have been varied to observe the performance of PSO. First of all, population is varied in the range 60-200 and it is observed that at population 80 it gives results even better than the population value of 100.

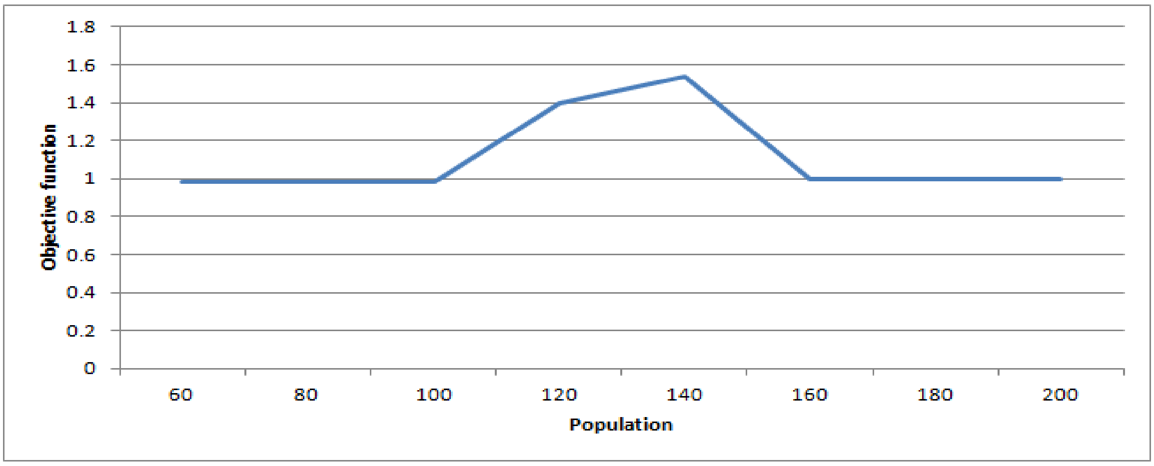

Fig 2: Population-Objective function plot of FIR Band-pass filter

The objective function value starts increasing after 100 and beyond 160 drops down to constant value. Furthermore now at this population factor of 80, the constants C_1 and C_2 are varied from 1.5 to 3.0 and it has been analyzed that on this parameter the value which was taken in the whole experiment of 2.0 yields best result compared to all.

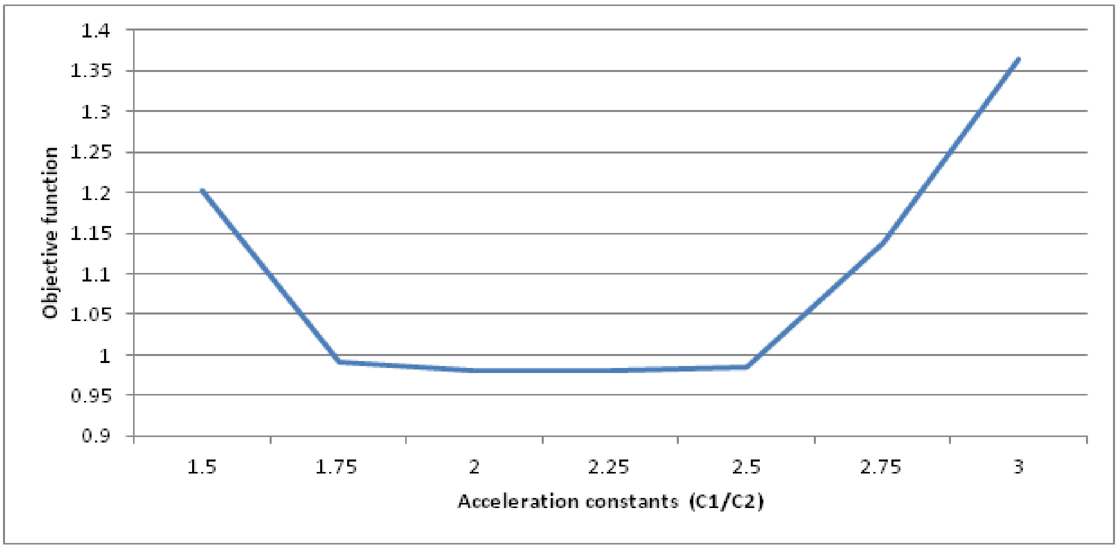

Fig 3: Acceleration constants-Objective function plot of FIR Band-pass filter

After best filter order is found out, magnitude response and phase response are plotted in MATLAB software as shown below:

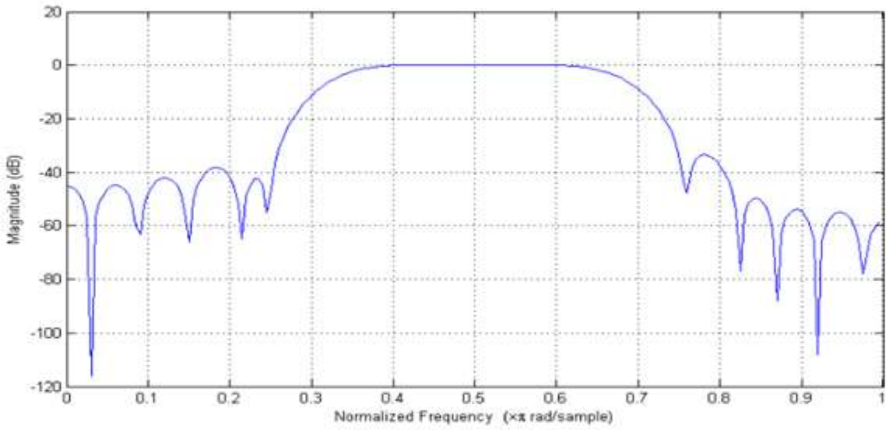

Fig 4: Magnitude response plot of FIR Band-pass filter

The magnitude response in db is plotted in the above Fig.4 for FIR Band-pass filter. The Band-pass filter follows the ideal pass-band and stop-band range i.e. $0.4\pi \leq \omega \leq 0.6\pi$ and $0 \leq \omega \leq 0.25\pi$, $0.75 \leq \omega \leq \pi$ which is shown respectively in Fig 4, Fig 5 and Fig 6.

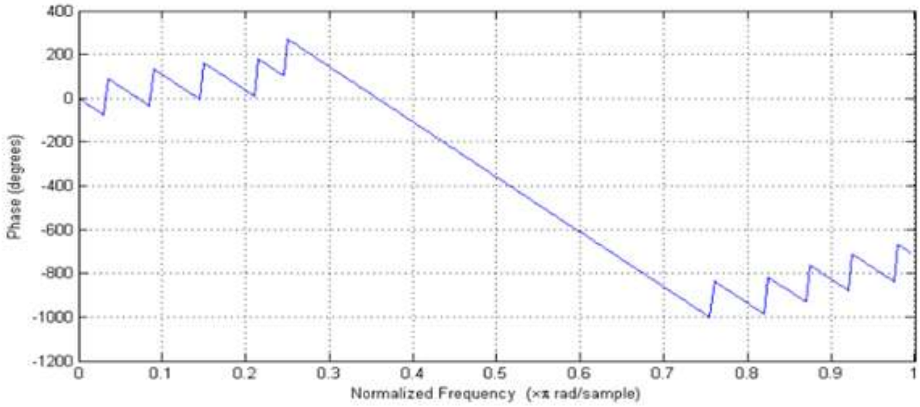

Fig 5: Phase response plot of FIR Band-pass filter

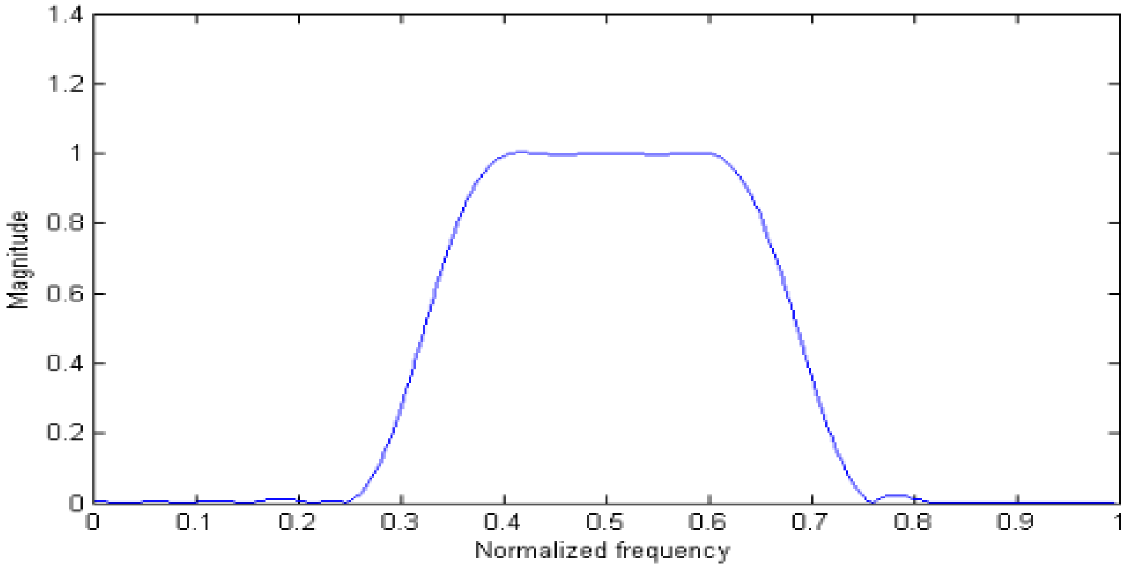

Fig 6: Normalized plot for FIR Band-Pass filter

The normalized magnitude response of FIR Band-Pass filter has been shown in Fig 6 above.

V. CONCLUSION

Particle Swarm Optimization is a technique developed by Eberhart and Kennedy in 1995 and is initialized with a population of random solutions called particles. This concept is quite similar to bird flocking behaviour. This technique is utilized for the designing of digital FIR Band-pass filter and the result is analysed. As it is obvious from the observation above, the FIR band-pass filter gives best results at filter order 28. Now furthermore the parameters were varied to tally the results with original values. When population factor was varied, it is observed that the designed filter gives better value at 80. Then on proceeding further the acceleration constants C_1 and C_2 were changed and found to be insensitive to variation and gave best result at value of 2.0 & 2.0 respectively. Thus the designed FIR Band-pass filter is stable and robust in nature. As future scope of work, by this technique one can also design low-pass, high-pass and band-stop filters.

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