A Comparison between Craziness based Particle Swarm Optimization and Particle Swarm Optimization for the Design of Digital FIR Band Pass Filter

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***Abstract*—Digital filters play an important role in the field of digital signal processing. Linear phase Finite Impulse Response (FIR) filters are used in numerous applications due to their nature of phase linearity as well as frequency stability. The design of Finite Impulse Response (FIR) digital band-pass filter using two population based global stochastic search technique have been implemented. Craziness based Particle Swarm Optimization (CRPSO) and Particle Swarm Optimization (PSO). CRPSO is the advance version of Particle Swarm Optimization. A comparison of CRPSO and PSO has been made on the basis of their control parameters. The achieved results show that the CRPSO Algorithm perform better than that of PSO in terms of achieved magnitude error and ripples in pass-band and stop-band.**

Keywords— Craziness based Particle Swarm Optimization, FIR Band Pass Filter, Particle Swarm Optimization

I. INTRODUCTION

A signal is defined as any physical quantity that varies with time, space, or any other independent variables. Basically signal is the carrier of information which is germinated in almost every field of science and engineering. The operation which modifies, analyzes and manipulates the information bearing signal is called signal processing. Signal processing have two subcategories named as analog signal processing (ASP) and digital signal processing (DSP) [9].

A digital signal processor is an integrated circuit which is designed for high speed data manipulation. DSP is used in variety of applications like audio, communications image manipulation, data acquisition and data control applications. DSP is the method of performing the mathematical operations on the signals in digital domain. The main objective of the DSP is to measure, filter and compress continuous real world analog signals. Real time signals are analog in nature [9].

In signal processing, a filter is essentially a network or system that are commonly used in signal processing and communication circuit systems to extract the useful portion of the signal and remove the unwanted portion such as random noise which could be generated due to unavoidable circumstances.

Filters are frequency selective devices that allow a certain range of frequency to pass while others are attenuated. This categorizes the filters into four different groups: i) Low Pass ii) High Pass iii) Band Pass iv) Band Stop Filters. Filters are also classified on the basis of input signal: i) Analog Filters ii) Digital Filters. Analog filters use electronic components such as resistors, capacitors and op-amps and operate on continuous time signals. On the other side, digital filter performs mathematical operation on a sampled, discrete time signal with the help of digital signal processor (DSP) to enhance the desired features of the applied signal. The major advantages of digital filters over analog filters are their small physical size, high accuracy and reliability [9].

Digital filters are divided into two broad categories depending on their impulse responses: Finite Impulse Response (FIR), Infinite Impulse Response (IIR). IIR filter have infinite impulse response. IIR filters are known as recursive filter. IIR filters output depend on the past and present inputs also. FIR filters are known as non recursive filters because of absence of feedback in the circuit. The output of the filter depends only on the present input. FIR filters having a finite impulse response with in a finite time. The main advantages of the FIR filter over the IIR filter, linear phase and stability whereas IIR filter has nonlinear phase and are not stable. Digital FIR filters involve only zeroes and digital IIR filters involves both poles and zeroes [1, 4].

Optimization is the process of selecting best element from the set of available elements regarding to the specified criteria. It can be described as a process of finding the condition that gives the optimum value of objective function. There are many types of optimization techniques which are used to design the digital FIR filters such as Genetic Algorithms (GA), Ant colony Optimization (ACO), Artificial Bee Colony (ABC), Particle Swarm Optimization (PSO), Predator Prey Optimization (PPO) and Differential Evolution [10].

Particle Swarm Optimization technique was developed by Eberhart and Kennedy in 1995. PSO is a flexible, robust population based stochastic optimization algorithm. This optimization technique requires no gradient and achieves a global optimal solution for the given multimodal objective function minimization in digital design problems. PSO is easy to implement when compared to other methods and its convergence can be controlled with few parameters only. The speed of the PSO algorithm is very fast. It is based on the swarm intelligence. It can be useful for the both engineering use and scientific research fields [10].

The limitations of the classical PSO are premature convergence and stagnation problem. To overcome these problem, an improved version of PSO, called craziness based particle swarm optimization (CRPSO) technique is used which is improved version of PSO and employed for FIR band pass filter design. The CRPSO algorithm tries to find the best coefficients that are closely match to the ideal frequency response and it presents the effectiveness, comprehensive set of results and better performance of the applied designed algorithm [2].

This paper is arranged as follows: In section II, the FIR band pass filter design problem is formulated. Section III presents a summary of the Optimization techniques and basic steps involved. Section IV consists of the simulation results that are obtained for Band Pass FIR digital filter. Finally, Section V concludes the paper.

II. FIR FILTER DESIGN PROBLEM

FIR filters are known as non recursive filters because the absence of the feedback in the circuit. The output of the FIR filter depends only on the present input. FIR filters having a finite impulse response with in a finite time. The main advantage of the digital FIR filter structure is that it can easily achieve exact linear phase frequency response. For Digital FIR Filter, design problem can be declared as (i) the highest tolerable pass-band ripple, (ii) the highest tolerable stop-band ripples, (iii) the pass-band edge frequencies, (iv) the stop-band edge frequencies.

Difference equation of FIR Filter is shown as below:

$$y(n) = \sum_{k=0}^{M-1} c_k\, x(n-k) \qquad (1)$$

M is selected as the length of filter. M-1 is the order of filter. The output $y(n)$ is the function of input signal $x(n)$, c_k is coefficient.

The transfer function of FIR filter is identified by:

$$H(z) = \sum_{k=0}^{M-1} c_k Z^{(-k)} \qquad (2)$$

The unit sample response of the digital FIR system is identical to the coefficients $\{c_k\}$, that is defined as:

$$h(n) = \begin{cases} c_k, & 0 \le n \le M-1 \\ 0, & \text{otherwise} \end{cases} \qquad (3)$$

An FIR filter has linear phase response if its unit sample response satisfies the following condition:

$$h(n) = \pm h(M-1-n) \qquad (4)$$

$$\mathrm{H}(\omega, x) = c_0 + c_1 e^{-j\omega} + \cdots + c_{M-1} e^{-j(M-1)\omega} \qquad (5)$$

$$\text{where } x = [c_0,\ c_1,\ c_2 \ldots\ldots c_{m-1}]^T \qquad (6)$$

$H_d(\omega_i) =$ Desired magnitude response

$H(\omega_{i,}x) =$ Obtained magnitude response

The absolute error $e_1(x)$ and squared error of magnitude response $e_2(x)$ are defined as given below:

$e_1(x)$ = absolute error L_1 norm of magnitude response.

$e_{2(x)}$= squared error L_2 norm of magnitude response.

$$e_1(x) = \sum_{i=0}^{k} \left| H_d(\omega_i) - |H(\omega_i, x)| \right| \qquad (7)$$

$$e_2(x) = \left\{ \sum_{i=0}^{K} \left| H_d(\omega_i) - |H(\omega_i, x)| \right|^2 \right\}^{1/2} \qquad (8)$$

Desired magnitude response:

$$H_d(\omega_i) = \begin{cases} 1, for\ \omega_i \in passband \\ 0, for\ \omega_i \in stopband \end{cases} \qquad (9)$$

The ripple magnitudes of pass band $\delta_1(x)$ and stop band $\delta_2(x)$ are to be minimized. Ripple magnitudes are defined as:

$$\delta_1(x) = \max_{\omega i} \{|H(\omega_{i,}x)|\} - \min_{\omega i} \{|H(\omega_{i,}x)|\} \qquad (10)$$

For $\omega_p \in$ passband

$$\delta_2(x) = \max_{\omega_i} \{|H(\omega_i, x)|\} \qquad (11)$$

For $\omega_s \in$ stopband

Aggregating all objectives, the multi-criterion constrained optimization problem is affirmed as:

$$Minimize\ O_1(x) = e_1(x) \qquad (12a)$$
$$Minimize\ O_2(x) = e_2(x) \qquad (12b)$$
$$Minimize\ O_3(x) = \delta_1(x) \qquad (12c)$$
$$Minimize\ O_4(x) = \delta_2(x) \qquad (12d)$$

In numerous-condition constrained optimization problem for the design of the design of digital FIR filter a single optimal tradeoff point can be set up with following expression [3]:

$$O(x) = \sum_{i=1}^{4} \omega_i\, O_i(x) \qquad (13)$$

The prescribed design condition for the design of band-pass Digital FIR Filter has been given in Table 2.1 below.

Table-2.1: Prescribed design condition for the design of band-pass Digital FIR Filter

Filter Type	Pass-Band	Stop-Band
Band-Pass	$0.4\pi \le \omega \le 0.6\pi$	$0 \le \omega \le 0.25\pi$ $0.75 \le \omega \le \pi$

III. OPTIMIZATION METHODOLOGY

Optimization is the minimization or maximization of an objective function value. Optimization algorithms are becoming popular day by day because of the availability and affordability of high speed computers. Optimal digital FIR band pass filter is designed using different optimization techniques. In this paper two optimization techniques have been applied, Particle Swarm Optimization and Craziness based Particle Swarm Optimization which are discussed in detail as follow [7, 5]:

A. Particle Swarm Optimization

One of the simplest optimization techniques is Particle Swarm Optimization which was discovered by Eberhart and Kennedy. PSO is robust and flexible optimization technique. PSO optimization techniques with implicit parallelism can be easily handled with non-differential objective function, unlike conventional optimization techniques. PSO is population based optimization technique. The population of the algorithm is called swarm. Member of the swarm is called particle. Personal best position of a given particle is called pbest (personal best). Position of the best particle member of the neighborhood of a given particle is called lbest (local best). Position of the best particle of the entire swarm is called gbest (global best). PSO has two important operators namely velocity update and position update. For the duration of each generation, every particle is accelerated on the way to the particle's previous best position and the global best position. A collection of particles are randomly set into motion through this search space. The new velocity is then used to calculate the next generation of the particle in the search space [7, 8, 11].

The velocity and position updating is exempted using particle Eq (1.14), Eq (1.15) & Eq (1.16) as given below:

$$v_{id}^{t+1} = w * v_{id}^{t} + c_1 * rand() * (p_{id}^{t} - x_{id}^{t}) + c_2 * Rand() * \left(p_{gd}^{t} - x_{id}^{t}\right) \quad (14)$$

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \quad (15)$$

$$w = w_{max} - (w_{max} - w_{min})^{\,IT/MAXIT} \quad (16)$$

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.

p_{id} represents the individual best.

p_{gd} represents the global best.

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 .

Algorithm of PSO

The steps involved for the global version of PSO are written as follows:

1) Initialize the population velocities in the d-dimensional search space.
2) Examine the desired optimization fitness function for all particles.
3) Now, compare the observed fitness value with the swarm particle's pbest. If the fitness function value is better as compared to the pbest, then set the value of pbest equal to the present value and also the pbest location to the same as current location in d-dimensional space.
4) After this, compare the fitness evaluation value with population's overall previous best value, if the fitness evaluation is better than gbest then update gbest value to current particle's array index and value.
5) After finding the pbest and gbest value, change the velocity and position of the particle according to Eq (14), Eq (15) and Eq (16).
6) Go to step 2 until gbest and pbest values obtained.
7) End [11].

B. Craziness based Particle Swarm Optimization

CRPSO methodology is modified from PSO. CRPSO has a special feature like sudden change velocity, craziness factor and change of direction of flying to words an apparently non promising area of food depends upon the particle mood. In the craziness based particle swarm optimization technique velocity can be defined as follows:

$$v_i^{(t+1)} = r_2 * sign(r_3) * v_i^{(t)} + (1 - r_2) * C_1 * r_1 * \{pbest_i^t - S_i^t\} + (1 - r_2) * C_2 * (1 - r_1) * \{gbest^t - S_i^t\} \quad (17)$$

where r_1, r_2 and r_3 are the random parameters uniformly taken from the interval [0,1] and sign (r_3) is a function expressed as follows:

$$sign(r_3) = \begin{cases} -1 \text{ where } r_3 \le 0.05 \\ 1 \text{ where } r_3 < 0.05 \end{cases} \quad (18)$$

$rand_1$ and $rand_2$ are two parameters independent parameters that are used in PSO. If both are small then both the social and personal experiences are not used full and convergence speed is decreased. So instead of using independent parameters single parameter is used so r_1 is large and 1-r_1 is small and vice-versa. To control the balance between local and global searches r_2 random parameter is introduced. In the bird's flocking, a bird often changes its direction suddenly. This is defined by a craziness factor and modeled in the methodology by using a craziness variable. A craziness operator is introduced. Before updating the position of particles the velocity of particle is crazed by:

$$V_i^{(t+1)} = V_i^{(t+1)} + P(r_4) * sign(r_4) * v^{craziness} \quad (19)$$

where r_4 is a random parameter which is chosen uniformly within the interval [0, 1], $v^{craziness}$ is a random parameter which is uniformly chosen from the interval [v_i^{min}, v_i^{max}] and P(r_4) ,sign(r_4) are defined as:

$$P(r_4) = \begin{cases} -1, where \quad r_4 \le P_{cr} \\ 0, where \quad r_4 > P_{cr} \end{cases} \quad (20)$$

$$sign(r_4) = \begin{cases} -1, where\ r_4 \ge 0.5 \\ +1, where\ r_4 < 0.05 \end{cases} \quad (21)$$

where P_{cr} is a predefined probability of craziness. The steps of CRPSO as implemented for linear phase FIR band pass filter design is as follows:

1. Initialize the population for a swarm of n_p vectors, in which every vector represents a solution of filter coefficient values.
2. Computation of initial cost (fitness) values of the total population, n_p.
3. Take the particle with the best fitness value or minimum fitness value that is global best (gbest) and personal best (pbest).
4. Compare the newly calculated fitness value with previous one and select the one having better fitness value as personal best (pbest).
5. Update velocity of particles as per Eq (17) and Eq (19) and position of particles as per Eq (15).
6. Update the pbest and gbest vectors and replace the updated particle vectors as initial particle vectors.
7. Iteration continues till the maximum iteration cycles or the convergence of minimum cost values are reached [6, 2].

IV. SIMULATION RESULTS

FIR band-pass Digital Filter has been designed using Particle Swarm Optimization technique and Craziness Particle Swarm Optimization. The both algorithms have been executed by 100 times and 200 iterations to design the Digital FIR band-pass filter.

A. Comparision Between PSO and CRPSO

The orders from 20 to 36 have been varied to obtain the minimum objective function. CRPSO and PSO have been applied to design FIR Band Pass filter with order from 20 to 36. Fig. 4.1 shows the graph of PSO verses CRPSO and it is plotted between different orders of filter and objective function. The minimum objective function (1.277338) is achieved at the filter order 28 with CRPSO as compared to PSO.

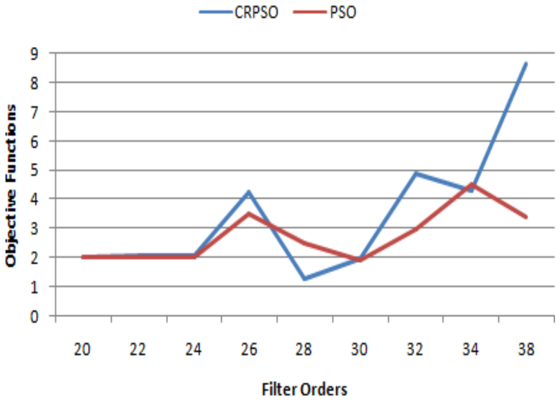

Fig.4.1: Graph between Filter Orders and Objective Function for CRPSO and PSO

For the design of Band-Pass Digital FIR Filter by implementing PSO and CRPSO the comparison in terms of parameters have been drawn in Table-4.1 below:

Table-4.1: Comparision of parameters of CRPSO and PSO

Parameters	CRPSO	PSO
Filter Order	28	28
Population Size	110	100
Accelartion Constant	0.2	0.2
P_{cr}	-	0.2
$V_{Craziness}$	-	0.0001

Table 4.2: Design Results for Digital FIR Band Pass Filter.

Parameters	CRPSO	PSO
Magnitude Error 1	0.846234	1.406852
Magnitude Error 2	0.133962	0.196262
Pass-band Performance	0.008517	0.014578
Stop-band Performance	0.060822	0.075343

Table-4.3: Comparison of CRPSO and PSO with Optimized Band Pass FIR Filter coefficients of Order 28

Sr. No.	No. of Coefficients	Values of Coefficients CRPSO	Values of Coefficients PSO
1	A(0)=A(28)	-0.006525	0.002362
2	A(1)=A(27)	-0.005029	0.001210
3	A(2)=A(26)	0.013993	-0.016115
4	A(3)=(25)	0.001782	0.001986
5	A(4)=A(24)	0.007180	0.000286
6	A(5)=A(23)	0.0008493	-0.003186
7	A(6)=A(22)	-0.052160	0.051421
8	A(7)=A(21)	-0.008571	-0.000301
9	A(8)=A(20)	0.036106	-0.043963
10	A(9)=A(19)	-0.004252	0.003411
11	A(10)=A(18)	0.100029	-0.093945
12	A(11)=A(17)	0.012346	-0.001759
13	A(12)=A(16)	-0.288062	0.291579
14	A(13)=A(15)	-0.006661	-0.000386
15	A(14)	0.376800	-0.385969

Table 4.4: Achieved Objective Function For Filter Order 28 for CRPSO and PSO

Objective Function	CRPSO	PSO
Minimum Value	1.277338	2.510969
Maximum Value	1.756396	2.58892
Averagev Value	1.683367	2.518715
Standard Deviation	0.009659	0.016295

CRPSO gives better performance and minimum objective function. The design results for Digital FIR Band Pass have been depicted in Table 4.2. Table 4.3 shows the best optimized filter coefficients shows the best optimized filter coefficients obtained for BP filter with the order of 28 by PSO and CRPSO. For both Craziness based Particle Swarm Optimization and Particle Swarm Optimization, the achieved value of Standard Deviation for objective function is less than 1 which authenticates the robustness of the designed band-pass FIR Digital filter which is shown in Table 4.4.

B. Analysis of Magnitude and Phase Response

After best technique has been found out, magnitude response and phase response are plotted in MATLAB software as shown below:

Magnitude Response:

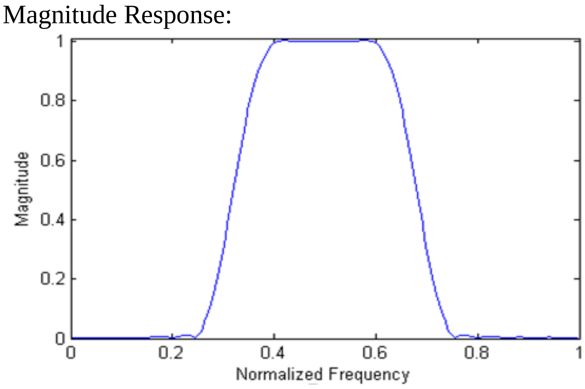

Fig.4.2: Magnitude Response for Band-pass Digital FIR Filter with CRPSO Algorithm

Phase Response:

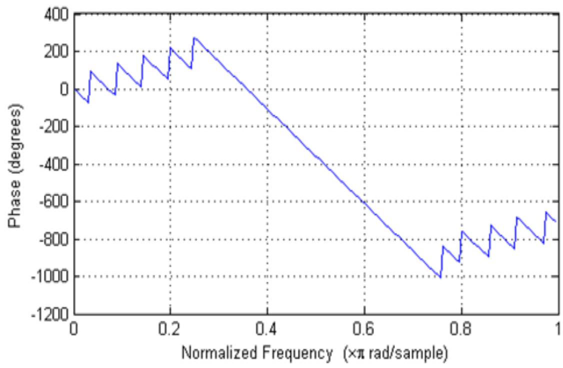

Fig.4.3: Phase Response for Band-pass Digital FIR Filter with CRPSO Algorithm

V. CONCLUSION

This paper presents an accurate method for designing digital band pass FIR filters by using CRPSO as a much improved version of PSO. The two heuristic optimization techniques namely Particle Swarm Optimization and

Craziness based Particle Swarm Optimization have been explored for the design of band-pass digital FIR filter. The results of both techniques have been compared in terms of magnitude errors and ripples in pass band and stop band along with the order of filter by optimizing various control parameters of Particle Swarm Optimization and Craziness based Particle Swarm Optimization algorithm. The results presented in this paper depict that CRPSO algorithm is better than PSO for solving the optimization problems. From the achieved value of Objective function, it is concluded that both PSO and CRPSO are robust in nature and CRPSO gives better results as compared to Particle Swarm Optimization.

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