Design of Digital Band Stop FIR Filter using Craziness Based Particle Swarm Optimization (CRPSO) Technique

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ABSTRACT

This paper presents the evolutionary optimization technique called craziness based particle swarm optimization (CRPSO) for the design of a digital band stop FIR filter. CRPSO is the much improved version of PSO, that proposes a new definition for the velocity vector and swarm updating and hence the solution quality is improved. It is a population based global stochastic search algorithm which finds near optimal solution in terms of a set of filter coefficients. Performance of proposed optimization technique is compared with some well established algorithm such as particle swarm optimization (PSO). From the simulation results it has been demonstrated that the proposed algorithm CRPSO can optimize the digital FIR filter in terms of minimizing the magnitude errors and minimizing the ripple magnitudes of both pass band and stop band.

Keywords- *Craziness based particle swarm optimization (CRPSO), Finite impulse response (FIR) filter, Magnitude response, Particle swarm optimization (PSO).*

I. INTRODUCTION

Digital signal processing is an area of science and engineering that has developed to have a major and increasing impact in many key areas of technology including media, digital television, digital audio, mobile phone, biomedicine, CD. The smaller, powerful, faster, and cheaper digital computers have developed due to the rapid developments of DSP in integrated-circuit technology, start with medium-scale integration (MSI) and succeeding to large-scale integration (LSI), and now, very-large-scale integration (VLSI) of electronic circuits. Due to these cheaper and relatively fast digital circuits have made it possible to construct highly complicated digital systems that are capable of performing complex digital signal processing functions and tasks, which are too expensive and usually complicated to be performed by analog circuit or analog signal processing systems. To process the analog signal, digital signal processing provides an alternative method. To perform the processing digitally, an interface is needed between the analog signal and the digital signal processor. This interface is called an analog-to-digital (A/D) converter. The output of the A/D converter is a digital signal that is given to the digital signal processor. The digital signal processor may be a digital computer to perform the desired operations on the input signal. Digital signal processing (DSP) is the mathematical manipulation of an information signal to modify or to improve it [1]. The advantages of DSP are its more efficient, simple to store and use, inexpensive, applicable to very low frequency signals and easy to construct [2].

The processing of signal mainly includes filtering which means to extract the information from the signal to remove unwanted part of signal and to improve signal quality. In engineering applications different filtering operations are to be performed for which different filters are required such as low pass, high pass, band pass, band reject, all pass, differentiator, integrator etc. A filter is basically a network or system that is widely used in signal processing and communication circuit systems to remove or at least unwanted parts of the signal such as noise. Based on the input signal, filters are classified as: analog filters and digital filters. Analog filters are the device that operates on continuous-time signals. These filters consist of passive and active basic elements of electronics like operational amplifiers, capacitors, resistors etc and these are easy to develop and especially cheap as compared with digital filters. Digital filters consist of DSP processors and controller which plays an important role in DSP applications such as signal analysis and estimation. In signal processing, a digital filter is a system that performs numerical operations on sampled values of signal, discrete signal to reduce or improve certain aspects of that signal. Digital filters may be more expensive than analog filters due to their complex structure, but they make practical many designs that are not practical or impossible as analog filters.

Digital filters are classified as infinite impulse response (IIR) and finite impulse response (FIR) on the basis of their impulse response. The impulse response of IIR filter is infinite, means unit sample response exists for zero to infinity. These are non linear and recursive type filters. A recursive type filter has feedback from output to input, in general its output is a function of the previous output samples and the present and past input samples. The impulse response of FIR filter is finite. This means the impulse response of FIR filters settles to zero with in a finite amount of time. FIR filters are called non-recursive as they have no feedback [3]. The advantage of FIR filter over IIR filters are, FIR filter contain linear phase by making the coefficients symmetrical whereas IIR filter has no particular phase. FIR filter always remain stable and depends only on input. FIR filters have only zeros and IIR filters consist of both poles and zeros.

Conventionally, there are many well known methods for FIR design, such as the window method, frequency sampling method, optimal filter design method. The windowing method simply consists of truncating or windowing a theoretically filter impulse response by some suitably chosen window function. The window method is fast, suitable, robust but generally suboptimal. There are various kinds of window functions (Butterworth, Chebyshev, Kaiser, and Hamming) available depending on the filter specifications like ripples in pass band, stop band, maximum stop band attenuation and on transition width [4]. Its major disadvantage is the lack of accurate control of the critical frequencies such as pass band and stop band cut-off frequency and the transition width. The objective function for the design of optimal digital filters involves accurate control of various parameters of frequency spectrum and is highly non-uniform, non-linear, non-differentiable and multimodal in nature. These objective functions cannot optimize. So, to design the optimal digital FIR filters, evolutionary optimization methods like GA [5], simulated annealing and artificial bee colony optimization have been implemented which are quite efficient and having better control of parameters. Genetic algorithms is efficient to obtain local optimum while maintaining its moderate computational complexity but it is not very successful in determining the global minima in terms of convergence speed and solution quality.

In this paper evolutionary optimization technique of Particle Swarm Optimization (PSO) for the design of digital band stop FIR filter is presented. Particle Swarm Optimization (PSO) was developed by Eberhart and it is evolutionary algorithm [6]. The merits of PSO are simple to implement and its convergence may be controlled via few parameters. But it contains limitations that are premature convergence and stagnation problem. To overcome these limitations, craziness based particle swarm optimization (CRPSO) technique is used which is modification to PSO and employed for FIR band stop 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 proposed designed method.

This paper is arranged as follows. In section II, the FIR band stop filter design problem is formulated. Section III briefly discusses the algorithm of classical PSO and the CRPSO. Section IV consists of the simulation results that are obtained for Band stop FIR digital filter. Finally, section V concludes the paper.

II. FIR FILTER DESIGN PROBLEM

FIR filter is known as non-recursive filter which means there is no feedback connection. The impulse response of FIR filter is finite. This means that the impulse response sequence of FIR filters has a finite number of non-zero terms. For the realization of FIR systems present, past, future samples of input are required. The conventional design of FIR digital filter is described by the difference equation and it is expressed as:

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

Here b_k is the set of filter coefficients. M is order of filter.

The transfer function of FIR filter is given as:

$$H(z)=\sum_{n=0}^{N} h(n) z^{-n}\ , \quad n=0,1,\ldots,N \tag{2}$$

Where $H(z)$ is the frequency domain representation of the impulse response and is termed as system function of the digital filter, $h(n)$ is the time domain representation of the impulse response of the filter, N is the order of the filter. This paper presents the FIR with $h(n)$ as even symmetric and the order is even. The length of $h(n)$ is N+1 and the number of coefficients are also N + 1. $h(n)$ coefficients are symmetrical so that dimension of the problem is halved. Thus, $\left(\frac{N}{2}+1\right)$ number of h(n) coefficients are actually optimized, which are finally coupled to find the required (N+1) number of filter coefficients.

The frequency response of a desired FIR filter is given as:

$$H_d\left(e^{j\omega}\right)=\sum_{n=0}^{N} h(n)e^{-j\omega n} \qquad (3)$$

Here $H_d\left(e^{j\omega}\right)$ is called the Fourier transform complex factor.

For a BS filter the ideal response is defined as:

$$H_i\left(e^{j\omega}\right)=\begin{cases}0 & for \quad \omega_{c1}\le\omega\le\omega_{c2}\\ 1 & otherwise\end{cases} \qquad (4)$$

ω_{c1}, ω_{c2} are the cutoff frequency of the ideal band stop filter.

The performances of digital FIR filter can be calculated by using L_1-norm and L_2-norm approximation error of magnitude response and ripple magnitude of both pass-band and stop-band. The FIR filter is designed by optimizing some coefficients or parameters so that L_p-norm approximation error function for magnitude is to be minimized. L_p-norm is expressed as [7]:

$$E(x)=\left\{\sum_{i=0}^{K}\left|H_d(\omega_i)-\left|H(\omega_i,x)\right|\right|^p\right\}^{1/p} \qquad (5)$$

Where $H_d(\omega_i)$ is the desired magnitude response of the ideal FIR filter and $H(\omega_i,x)$ is the obtained magnitude response of the FIR filter.

For p=1, magnitude error denotes the L_1- norm error and for p=2 magnitude error denotes the L_2-norm error.

L_1-norm error, $e_1(x)$ of magnitude response is stated as below:

$$e_1(x)=\sum_{i=0}^{K}\left|H_d(\omega_i)-\left|H(\omega_i,x)\right|\right| \qquad (6)$$

And the squared L_2-norm error, $e_2(x)$ of magnitude response is stated as below:

$$e_2(x)=\left\{\sum_{i=0}^{K}\left|H_d(\omega_i)-\left|H(\omega_i,x)\right|\right|^2\right\}^{1/2} \qquad (7)$$

The desired magnitude response $H_d(\omega_i)$ of FIR filter is given as:

$$H_d(w_i)=\begin{cases}1 & for \quad \omega_i \varepsilon \; passband\\ 0 & \quad \omega_i \varepsilon \; stopband\end{cases} \qquad (8)$$

δ_p and δ_s are the ripple magnitude of pass band and stop band which are to be minimized and these are expressed as:

$$\delta_p=\max\left|H(\omega_i,x)\right|-\min\left|H(\omega_i,x)\right| \quad for \;\; \omega_i \; \epsilon \; passband$$

$$\delta_s=\max\left|H(\omega_i,x)\right| \quad for \;\; \omega_i \; \epsilon \; stopband \qquad (9)$$

Four objective functions for optimization are:

$$f_1(x)=Minimize \;\; e_1(x)$$
$$f_2(x)=Minimize \;\; e_2(x)$$
$$f_3(x)=Minimize \;\; \delta_p$$
$$f_4(x)=Minimize \;\; \delta_s$$

The multi objective function is converted into single objective function:

$$Minimize \quad f(x)=\omega_1 f_1(x)+\omega_2 f_2(x)+\omega_3 f_3(x)+\omega_4 f_4(x) \qquad (10)$$

$\omega_1, \omega_2, \omega_3, \omega_4$ are the weighting function

III. EVOLUTIONARY TECHNIQUE EMPLOYED

1. Classical PSO

PSO is a flexible, robust population-based stochastic search or optimization technique that is based on the intelligence and movement of swarms. PSO can easily handle non-differential objective functions and larger search space unlike traditional optimization methods. PSO was originally invented by James Kennedy and Russell Eberhart after being inspired by the study of the behavior of bird flocking and fish schooling. From the inspiration of nature, it consists of a number of particles that make the swarm and moving in the search space to look for the best solution. Each particle is behaved as an independent point in search space which adjusts its position according to their own flying experience and their neighbor's flying experience. In the search space each particle has some fitness value that has been achieved by that particle so far. This value is known as personal best (pbest). Also, there is another best value that is obtained so far by any particle in the neighborhood of that particle in the search space. This value is known as global best (gbest). So after finding the pbest and gbest values, the particle updates their velocity and positions by using these two equations [8]:

$$V_i^{(k+1)}=w*V_i^{(k)}+C_1*rand_1*\left\{pbest_i^{(k)}-X_i^{(k)}\right\} + C_2*rand_2*\left\{gbest_i^{(k)}-X_i^{(k)}\right\} \qquad (11)$$

$$X_i^{(k+1)}=X_i^{(k)}+V_i^{(k+1)} \qquad (12)$$

Where $rand_1$ and $rand_2$ are random numbers chosen between 0 and 1, w is the weighting function and will be updated by progressively iterations

$$w = w_{\max} - (w_{\max} - w_{\min}) * \left(\frac{IT}{\max IT} \right)$$

$w_{\max}$ is the maximum value of weighting function, $w_{\min}$ is the minimum value of weighting function and $\max IT$ are the maximum iterations, $V_i^{(k)}$ is velocity of a particle at k^{th} iterations, $X_i^{(k)}$ is current particle value at k^{th} iterations, C_1 and C_2 are learning factors having value 2.

Here two random parameters $rand_1$ and $rand_2$ of (11) are independent. If both are large, the particle is driven too far away from the local optimum. If both are small, the convergence speed of the technique is reduced. So, instead of taking $rand_1$ and $rand_2$ independent one single random number r_1 is chosen so that when r_1 is large, $(1-r_1)$ is small and vice versa. Another random parameter r_2 is introduced to control the balance of global and local searches. The global search ability of PSO is improved with the help of the following modifications. This modified PSO is termed as improved particle swarm optimization (IPSO).

With all modifications, the velocity can be expressed as follows [9]:

$$V_i^{(k+1)} = r_2 * sign(r_3) * v_i^{(k)} + (1-r_2) * C_1 * r_1 * \left\{pbest_i^{(k)} - X_i^{(k)}\right\} + (1-r_2) * C_2 * (1-r_1) * \left\{gbest_i^{(k)} - X_i^{(k)}\right\} \quad (13)$$

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 defined as:

$$sign(r_3) = \begin{cases} -1 & where \quad r_3 \le 0.05 \\ +1 & \quad\quad\quad r_3 > 0.05 \end{cases} \quad (14)$$

For birds flocking for food, there could be some rare cases that after the position of the particle is changed according to (12), the direction of bird's velocity will be opposite to the sure area of food due to inertia. So, in that case the direction of the bird's velocity should be reversed. Sign(r_3) is used to ensure the flying direction always towards the promising regions.

2. Craziness Based Particle Swarm Optimization (CRPSO)

A craziness operator is introduced in the proposed technique to ensure that the particle would have a predefined craziness probability to maintain the diversity of the particles. Before updating its position the velocity of the particle is crazed by [10]:

$$V_i^{(k+1)} = V_i^{(k+1)} + P(r_4) * sign(r_4) * v^{craziness} \quad (15)$$

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:

$$P(r_4) = \begin{cases} -1 & where \quad r_4 \le P_{cr} \\ 0 & \quad\quad\quad r_4 > P_{cr} \end{cases} \quad (16)$$

$$sign(r_4) = \begin{cases} -1 & where \quad r_4 \ge 0.5 \\ +1 & \quad\quad\quad r_4 < 0.05 \end{cases} \quad (17)$$

Where P_{cr} is a predefined probability of craziness. The steps of CRPSO algorithm are as follows:

1. Initialize the population for a swarm of n_p vectors, in which each vector represents a solution of filter coefficient.
2. Computation of initial cost (fitness) values of the total population.
3. Take the particle with the best fitness value or minimum fitness value i.e. global best (gbest).
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 using Eq.(13) and Eq. (15) and position of particles using Eq. (12).
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.

The design aim of this paper is to obtain the optimal combination of the filter coefficients, so as to acquire the minimum magnitude error and maximum stop band attenuation. The values of the parameters used for the CRPSO technique are given in Table 1. The designing of Band Stop FIR digital filter is done by setting 200 equally spaced points within the frequency domain [0, π]. The prescribed design conditions for the design of Band Stop FIR filter are given in Table 2.

Table 1
CRPSO parameters

Parameter	Value
Population size	100
Iteration cycle	200
C_1, C_2	2
v_i^{min}	0.01
v_i^{max}	1.0
P_{cr}	0.3
$v^{craziness}$	0.00001

Table 2
Desired Design Conditions for Band Stop Filter

Filter Type	Pass-band	Stop-band	Maximum value of H(ω,x)
Band stop	$0 \le \omega \le 0.25\pi$ $0.75\pi \le \omega \le \pi$	$0.4\pi \le \omega \le 0.6\pi$	1

IV. RESULTS AND DISCUSSIONS

This section presents the simulations performed in MATLAB for the design of FIR band stop (BS) filter. CRPSO has been applied to design FIR BS filter with order from 16 to 24 and the results are given in Table 3. Fig. 1 shows the graph of PSO verses CRPSO and it is plotted between different orders of filter and objective function. From figure 1 it is observed that objective function of CRPSO is less than PSO for all the orders and at 22 order objective function is minimum as compared to other orders. So order 22 is selected for designing FIR BS filter using CRPSO. Fig. 2 indicates the magnitude response in dB verses normalized frequency for band stop filter of order 22. The absolute magnitude response for band stop filter of order 22 has been shown in Fig.3. Fig.4 depicts the graph between objective function and no. of iterations. It is concluded that the magnitude gets stabilized after 40 iterations for band stop FIR filter. Table 4 shows the best optimized filter coefficients obtained for BS filter with the order of 22 by PSO and CRPSO. Table 5 indicates that the best value, average value and standard deviation of objective functions are much better for CRPSO than PSO which assured the effectiveness of the designed system. From Table 6 it may be noted that the maximum stop band attenuation achieved for BS filter of order 22 using the CRPSO is 39.75 dB and it is also observed from Table 6 that the simulation results obtained for filter order 22 using CRPSO are better than the PSO.

Table 3
Design Results for Band stop FIR Filter

Order	L_1- norm Error	L_2- norm Error	Pass-band performance (ripple magnitude)	Stop-band performance (ripple magnitude)
16	2.381177	0.271761	0.081645	0.077253
18	2.073546	1.322810	0.032898	0.096224
20	1.107620	0.124365	0.036641	0.027572
22	1.077585	0.116743	0.056717	0.010287
24	1.288776	0.157494	0.084807	0.084436

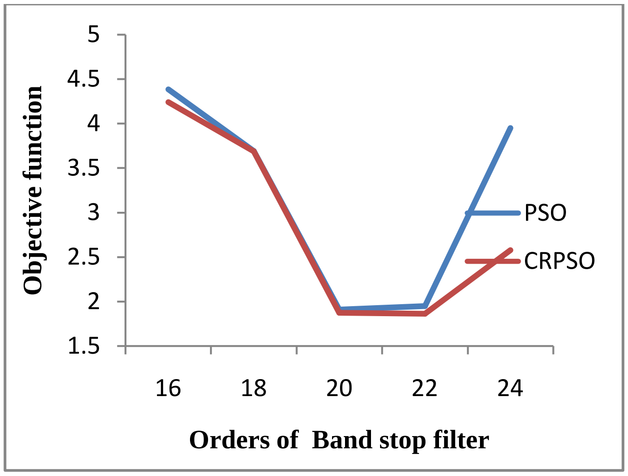

Fig. 1 Graph of PSO verses CRPSO

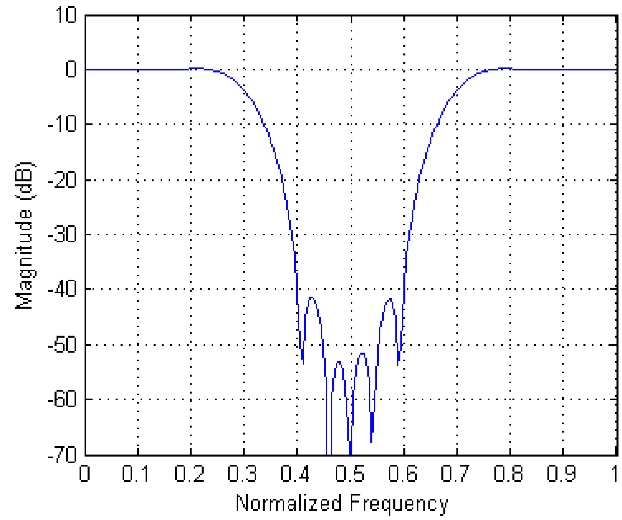

Fig. 2 Magnitude (dB) plot for the FIR BS Filter of order 22

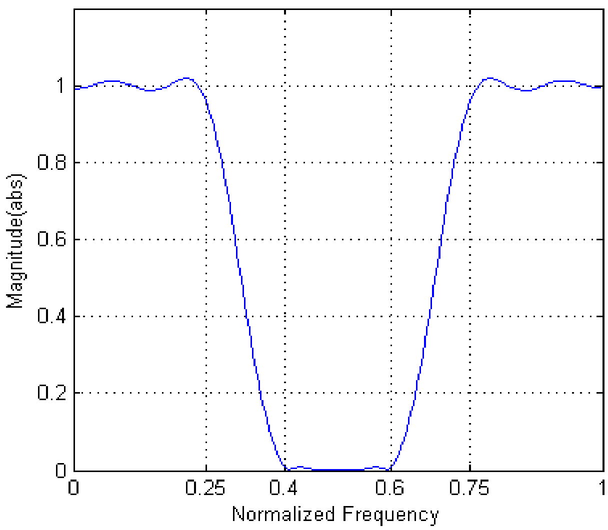

Fig. 3 Magnitude (abs) plot for the FIR BS filter Order2 22

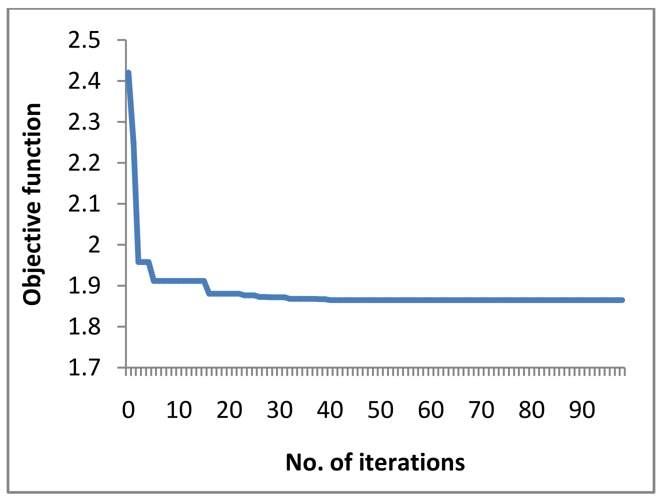

Fig.4 Objective function verses no. of iterations grap

Table 4
Optimized coefficients of FIR BS filter of order 22

h(filter coefficient)	PSO	CRPSO
h(1)=h(23)	.019188	.020067
h(2)=h(22)	.000155	.000168
h(3)=h(21)	-.016354	-.016814
h(4)=h(20)	.000165	.000255

h(5)=h(19)	-.038888	-.039883
h(6)=h(18)	-.000023	.000126
h(7)=h(17)	.100171	.101510
h(8)=h(16)	.000102	.000171
h(9)=h(15)	-.030329	-.029770
h(10)=h(14)	-.000001	-.000029
h(11)=h(13)	-.528980	-.530738
h(12)	-.000167	-.000153

Table 5
Statistical Data for FIR BS Filter of order 22

Algorithm	Maximum value of Objective function	Minimum value of Objective function	Average of Objective function	Standard deviation
PSO	1.952253	1.94822	1.948766	0.000708
CRPSO	1.866001	1.86436	1.865015	0.000373

Table 6
Summary of CRPSO results with PSO for FIR BS filter of order 22

Algorithm	BS filter			
	Objective Function	Maximum Stop-band attenuation(dB)	Maximum Pass-band ripple (normalized)	Maximum stop-band ripple (normalized)
PSO	1.948220	37.78	0.059699	0.012912
CRPSO	1.864360	39.75	0.056717	0.010287

From the results, it is evident that the proposed filter design approach CRPSO produces minimum objective function, higher stop band attenuation and smaller stop band ripple compared to PSO.

V. CONCLUSION

This paper presents a novel and accurate method for designing digital Band stop FIR filters by using CRPSO as a much improved version of PSO. Filter of order 22 have been realized using CRPSO algorithm. Simulation results show better performance of the proposed CRPSO algorithm in terms of objective function, magnitude error, and maximum stop band attenuation and CRPSO technique can also be used to design high pass, low pass and band pass filters.

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