Design Of Linear Phase Band Pass Finite Impulse Response Filter Based On Modified Particle Swarm Optimization Algorithm

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Abstract

Digital filters are elementary elements of Digital Signal Processing (DSP) scheme since they are extensively employed in numerous DSP applications. Finite Impulse Response (FIR) digital filter design has multiple factor optimizing, in which the current optimizing method does not work proficiently.

Swarm intelligence is a technique that forms the population of interrelated suitable agents or swarms for self-organization. A Particle Swarm Optimization (PSO) that stands for a populating and optimizing scheme with adaptively nonlinear functions in multidimensional space is a distinctive model of a swarm system.

The goal of this study is to explain a scheme of designing Linear Phase FIR filter based on an improved PSO algorithm called Modified Particle Swarm Optimization (MPSO). The simulated outcomes of this paper demonstrate that the MPSO method is finer than the conformist Genetic Algorithm (GA) in addition to the standard PSO algorithm with extra fast convergence rate and superior performance of the designed 30th order band pass FIR filter.

The FIR filter design by means of MPSO Algorithm is simulated using MATLAB programming language version 7.14.0.739 (R2012a).

Keywords: Modified Particle Swarm Optimization, FIR filter, Band Pass Filter, Evolutionary Optimization, Digital Signal Processing.

تصميم مرشحات امرار حزمة خطية الطور ذات استجابة اندفاع متناهية بالاعتماد على خوارزمية تحسين سرب الجسيمات المعدلة

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المستخلص

يعد الترشيح الرقمي احد الجوانب الرئيسة لمعالجة الاشارة الرقمية, لذلك تستخدم المرشحات الرقمية في العديد من تطبيقات معالجة الاشارة الرقمية (DSP). تصميم مرشح ذو استجابة اندفاع متناهية (FIR) ينطوي ضمن التحسين المتعدد الحدود, بحيث ان خوارزميات التحسين الموجودة حاليا لا تعمل بالكفاءة المطلوبة. خوارزمية تحسين سرب الجسيمات (PSO) هي خوارزمية تحسين مستوحاة من علم الاحياء والتي ثُبُتَ تجريبيا الاداء الجيد لها في العديد من مشاكل التحسين. وتستخدم هذه الخوارزمية على نطاق واسع لإيجاد الحل الامثل في فضاء البحث المعقد.

الهدف من هذه المقالة هو وصف طريقة تصميم مرشح خطي الطور ذو استجابة اندفاع متناهية بالاعتماد على خوارزمية تحسين سرب الجسيمات المعدلة (MPSO) تعد نوعاً محسناً من انواع خوارزمية تحسين سرب الجسيمات (PSO).

تظهر نتائج المحاكاة ان خوارزمية تحسين سرب الجسيمات المعدلة (MPSO) هي افضل من الخوارزمية الجينية (GA) وخوارزمية تحسين سرب الجسيمات (PSO) التقليدية من حيث سرعة التقارب نحو الحل الامثل والاداء.

تم محاكاة تصميم مرشح ذو استجابة اندفاع متناهية (FIR) باستخدام خوارزمية تحسين سرب الجسيمات (PSO) باستخدام برنامج الماتلاب نسخة 7.14.0.739 (R2012a).

الكلمات المفتاحية: خوارزمية تحسين سرب الجسيمات المعدلة - مرشح ذو استجابة اندفاع متناهية – التحسين التطوري – معالجة الاشارة الرقمية.

1. Introduction

For numerous decades ago and until now, DSP techniques have been imperative hypothetically and technically in all scopes of electrical, electronic and computer engineering. DSP systems can be classified into two types. The 1st ones execute time domain signal filtering and for this reason, they are called digital filters. The 2nd one offers signal version of frequency domain and they are called Spectrum Analyzer. Digital filtering stands for the mainly influential tools of DSP techniques in many wireless and communication systems [1].

The conformist method of filter design is by choosing one of the typical polynomial transfer functions that suit the response requirements. After that, the transfer function realization is performed in the adopted regular circuit formations. This method of filter design is usually insufficient and an optimizing procedures are needed [2 and 3].

Particle swarm optimization (PSO) had been initiated and expanded by Kennedy and Eberhart as an estimating and optimizing simulation method [4].In this optimizing method, every entity is known as “particle” and it stands for a prospective solution. It performs the most excellent solution by the changeability of several particles in the tracing space. The particles explore the solution space and the finest particle by varying their locations and fitness regularly. By the objective function, the velocity and flying route can be evaluated. To enhance the convergence behavior of PSO, the inertia weight factor (w) manages the impact on existing particle by previous particle’s velocity [5]. As a result of its numerous benefits of straightforwardness and simple realization, PSO optimization methods are adopted extensively in all branches of engineering and applied sciences [6].

The Genetic Algorithm (GA) is an evolutionary algorithms (EA) is used to replicate the experience of natural evolution.

For that, every species looks for the advantageous adjustments in an ever-changing surroundings. As species develop, the innovative elements are prearranged in the chromosomes of entity members. This chromosomes date are is changed by arbitrary mutation. However, the factual powerful force following the evolutionary expansion is the grouping and swapping the chromosomal matter throughout breeding stage [7].

Digital FIR filters comprise a number of realization advantages; the phase response can be accurately linear. These digital filters are comparatively simple to implement as there are no stability difficulties. They are resourceful for implementation, and the DFT is possible to be used in their realization [2 and 8].

In this study, Linear Phase Band FIR band pass filter using an improved PSO technique called Modified Particle Swarm Optimization (MPSO) is described and discussed with good performances.

This research is organized as follows: the 2nd section of this paper represents a summary of the interconnected works in the literature. The 3rd section explains hypothetical setting of digital FIR filter. The 4th section of this paper provides a preface about the Standard PSO algorithm. Section 5 gives an introduction to the Modified PSO algorithm. Section 6 gives an introduction to the conventional GA. Section 7 shows the planned FIR filter implementation scheme for the FIR filter. Section 8 shows the simulated outcomes of the 31 tap band pass FIR filter using MPSO and presents a performance assessment of the Modified Particle Swarm (MPSO) algorithm with that of conventional GA and standard PSO algorithms on band pass FIR filter design problem. Finally, section 9 presents the conclusion of this work.

2. Related Works

For related works regarding linear phase FIR filters, Genetic Algorithm (GA)has been used to construct linear phase FIR low pass filter with low and median taps [9] .In[10], a well-organized implementation of FIR digital filters with random amplitude and phase requirements by means of GA have been presented. In [11], the authors proposed a Chaotic Particle Swarm Optimization (CPSO) procedural steps to implement low pass FIR filters. In [12], a low pass FIR filter is implemented to fairly accurate prearranged magnitude properties concerning the transfer function coefficients using the PSO optimizing method with desired fitness with a number of adaptations to reach nearly to the preferred response. In [13], the cultural particle swarm optimization (CPSO), a new population-based search method has been presented to implement FIR filters. In [14], a new and precise technique to realize linear phase FIR high pass filter via optimizing method derived from Improved Particle Swarm Optimization (IPSO) is explained and discussed. In [15], a new Craziness Particle Swarm Optimization (CRPSO) procedure is used for the solution of the constrained, multimodal, non-differentiable, and extremely nonlinear band stop FIR filter design to obtain the best possible filter coefficients. In [16], a new PSO method is used to realize FIR low pass filter with finest filter specifications. In [17], the application of the PSO to design low pass and band pass FIR filters has been carried out, also a comparison with GA has been made. Finally in [18] the Modified Particle Swarm Optimization (MPSO) algorithm was employed in the designing of Adaptive IIR Filter for System Identification based on FPGA.

As mentioned above, the Modified Particle Swarm Optimization (MPSO) method has been used formerly in the Design of Adaptive IIR Filter for System Identification on

FPGA as in [18] while in this paper the MPSO has been used in the design of Linear Phase Band Pass Finite Impulse Response filter.

In this work, MPSO is not only adopted to implement Linear Phase FIR band pass filter and compare the simulation results with the Linear Phase Band Pass Finite Impulse Response (FIR) filter design via conservative GA and standard PSO procedural steps but also the influence of changing the particle swarm optimization (PSO) parameters such as the inertia weight (*w*),cognitive (c1)and social (c2) on the PSO-based band pass FIR filter design problem have been discussed and depending on this discussion, the Modified Particle Swarm Optimization (MPSO) parameters such as the highest inertia weight(w_{max}), smallest inertia weight(w_{min}), cognitive (c1)and social (c2) have been chosen.

3. Fir Filter

FIR filter can be defined based on its length *M* with input and output coefficients represented by *x(n) and y(n)* [19]:

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

$$= b_0 x(n) + b_1 x(n-1) + \ldots\ldots + b_N x(n-M+1)$$

b_k stands for the set of filter generic terms. On the other hand, the resulting series as the convolution of the unit sample response *h(n)* of the system with the inputted signal can be expressed by [19]:

$$y(n) = \sum_{k=0}^{M-1} h(k) x(n-k) \quad (2)$$

The minor and higher limits on the convolution summation reveal the finite-duration and causality features of the filter.

Noticeably, (1) and (2) are the same in appearance and for this reason; $b_k = h(k), k=0, 1, 2, \ldots, M-1$.
The filter can as well be distinguished by its system function [19]:

$$H(z) = \sum_{k=0}^{M-1} h(k) z^{-k} \quad (3)$$

The polynomial roots comprise the filter zeros. FIR filter is linear-phase only in the case of its coefficients are regular around the center coefficient [20] as well as its unit sample response agrees the following formula [19]:

$$h(n) = h(M-1-n) \; n = 0, 1, 2, \ldots, M-1 \quad (4)$$

If the symmetry circumstance is included, equation (5) can be expressed as [20]:

$$H(z) = h(0) + h(1)z^{-1} + \cdots + h(M-2)z^{-(M-2)} + h(M-1)z^{-(M-1)} \quad (5)$$

$$= z^{-(M-1)/2}\left\{ h\left[\frac{M-1}{2}\right] + \sum_{n=0}^{\frac{M-3}{2}} h(n)\left[z^{\frac{(M-1-2k)}{2}} \pm z^{-\frac{(M-1-2k)}{2}}\right]\right\} \qquad M \text{ odd}$$

$$= z^{-\frac{M-1}{2}} \sum_{n=0}^{\left(\frac{M}{2}\right)-2} h(n)\left[z^{\frac{(M-1-2k)}{2}} \pm z^{-\frac{(M-1-2k)}{2}}\right]\} \qquad M \text{ even}$$

In the case of $h(n) = h(M-1-n)$, $H(\omega)$ is written as[19]:

$$H(\omega) = Hr(\omega) e^{-\frac{j\omega(m-1)}{2}} \quad (6)$$

$H_r(\omega)$ stands for an actual function of ω and it is defined as[19]:

$$H_r(\omega) = h\left(\frac{M-1}{2}\right) + 2\sum_{n=0}^{\left(\frac{M-3}{2}\right)} h(n)\cos\omega\left(\frac{M-1}{2} - n\right) \qquad M\ odd \tag{7}$$

$$H_r(\omega) = 2\sum_{n=0}^{\left(\frac{M}{2}\right)-1} h(n)\cos\omega\left(\frac{M-1}{2} - n\right) \qquad M\ even \tag{8}$$

The phase attributes of the filter for *M* odd and *M* even is[19]:

$$\theta(\omega) = \begin{cases} -\omega\left(\frac{M-1}{2}\right), & if\ Hr(\omega) > 0 \\ -\omega\left(\frac{M-1}{2}\right) + \pi, & if\ Hr(\omega) < 0 \end{cases} \tag{9}$$

In the case of a symmetrical $h(n)$, the filter coefficients amount that identify its response is $(M + 1)/2$ if M is odd or $M/2$ as M is even.

Linear phase FIR filters comprise numerous gains since design problem has only real mathematical and not complex mathematics. Also, they present no delay deformation and just a constant delay amount, filter length M, the operations number are of the order of $M/2$[8].

In a nutshell, FIR filter implementation is clean to verify the M coefficients $h(n)$, $n = 0, 1, 2, \ldots, M-1$, from a condition of the preferred frequency response $H_d(w)$of the FIR filter[19].

4. STANDARD PSO METHOD

PSO makes a simulation of the bird flocking behaviors. It can be employed to resolve the optimizing issues. PSO is started with arbitrary particles group (solutions, X_i) and after that looks for the best values by generations update. Every particle is rebuilt by the subsequent dual "*best*" values. The 1st one is the best solution (*fitness*) it has realized so far. This is known as *pbest*(p_i). A different "*best*" magnitude which is directed by PSO tool is the most excellent magnitude, acquired so far by whichever particle in the population. This magnitude is a comprehensive best and known as *gbest*(p_g). The speed and locations of every particle is restructured along with their finest meeting location in addition to the finest location gotten together by every particle consistent with [21]:

$$V_{id} = w * V_{id} + c1 * rand() * (P_{id} - X_{id}) + c2 * rand() * (P_{gd} - X_{id}) \quad (10)$$

$$X_{id} = X_{id} + V_{id} \quad (11)$$

V_{id} represents the particle speed in d-dimension, X_{id} represents the present particle location (solution) in d-dimension, w is the inertia weight. p_i and p_g are described as explained previously, rand() is an arbitrary formula in the range [0,1]. $c1$ and $c2$ stand for the cognitive and social learning factors[21].

5. MODIFIED PSO ALGORITHM

The equation of PSO has three coefficients. The $c1$ and $c2$ are known as cognitive and social acceleration coefficients and they are useful to direct the particles on the way to the *gbest*. They are equal constants and ranged from 0 to 2. For MPSO method, w can be determined by [18]:

$$w = w_{max} - ((w_{max} - w_{min}) * iter) / iter_{max} \quad (12)$$

Here, w_{max} is the highest inertia weight, w_{min} is the smallest amount of inertia weight, *iter* represents current no. of iterations, $iter_{max}$ is maximum no. of iterations.
Additionally, the inertia weight (w) manage the present velocity effect on the updated velocity. A huge inertia weight requires big searching throughout the search space; a minor inertia weight leads to lessened searching. By equation (12), it is possible to renew w for sufficient searching of search space. Consequently, realizing the comprehensive best is a possible solution. Additionally, this highest velocity is restricted by Signum function. By velocity renewing or updating, particles acceleration can be acquired. Tiny acceleration can lessen the convergence velocity, while hugely big acceleration drifts the particles near infinity [18].

6. GENETIC ALGORITHM (GA)

GA is derived from the notion of “survival of the fittest”. It is optimizing technique that looks like ordinary selection. A numbers group that is possibly to be a problem solution at hand is known as chromosome. Numerous chromosomes are known as population. GA updates generations by using a number of inherited operations to the population individuals. GA procedures are [17]:

1. Produce preliminary population and evaluate score of every individual.
2. Selection of dual individuals for mating.
3. Mating or Crossover for these chosen individuals
4. Offspring Mutation.
5. Scores Evaluation of offspring
6. Do again steps from 2 to 5 in anticipation of an arranged offspring number is created.
7. Replacement of updated offspring into the population.

8. Do again steps from 2 to 57 as execution decisive factor is not satisfied.

The chromosomes encoding and evaluating function definition are imperative divisions of GA technique. The structure should stand for a problem solution. Evaluating function measures up chromosomes to a target and allocates a score to them. This optimization procedure employs scores to categorize the population chromosomes [17].

7. Fir Band Pass Filter Based on Mpso Method

For a linear phase FIR filter, an *M* tap FIR filter that will be approximately the same frequency response of the ideal band pass filter as depicted in Fig. (1) is intended.

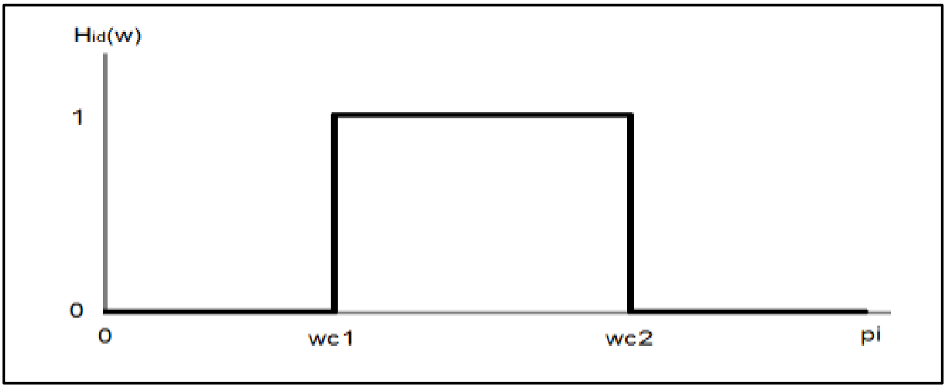

Figure1: Frequency response of an ideal Band Pass filter.

The FIR filter transfer function of order *N* is:

$$H(z) = \sum_{n=0}^{N} h(n) z^{-n} \qquad (13)$$

The equivalent frequency response can be found by:

$$H(e^{jw}) = \sum_{n=0}^{N} h(n)e^{-jn\omega} \qquad (14)$$

The transfer function can contain symmetric coefficients that is *h(n) = h(- n)* in linear phase case, so:

$$H(e^{j\omega}) = H(w)e^{j\phi(\omega)} \qquad (15)$$

Where

$$H(\omega) = h[\tfrac{N}{2}] + \sum_{n=1}^{N/2} \left(h[\tfrac{N}{2} - n][2\,cos(n\omega\,)]\right) \qquad (16)$$

At this time, the frequency can be sampled in [*0, π*] with *L* points,

$$Hd(\omega) = [\,Hd(\omega_1), Hd(\omega_2), \ldots\ldots, Hd(\omega L)]^T \qquad (17)$$

Such as in the case of $\omega c1 = 0.3\,\pi$ and $\omega c2 = 0.7\,\pi$, $H_d(\omega)$ equal to [00011111000] when 10 samples between 0 and piaretacked.

$$H(\omega) = [\,H(\omega_1), H(\omega_2), \ldots\ldots, H(\omega L)]^T \qquad (18)$$

The error function (Ɛ) at this instant is:

$$\mathcal{E}(\omega) = [\,Hd(\omega) - \;H(\omega)\,] \qquad (19)$$

The fitness function in this study represents the summation of the absolute magnitudes of the error function □ *(H)*:

$$fitness = \sum_{1}^{L} abs(\mathcal{E}(\omega)) \tag{20}$$

So, MPSO method can be adopted to determine the impulse response, and the input matrix input to the PSO is:

$$h = h\left[\frac{N-1}{2}\right], h\left[\frac{N-1}{2}+1\right], \dots\dots\dots\dots h[N-1] \tag{21}$$

The flow chart of the MPSO-based band pass FIR filter design is shown in Fig. (2).

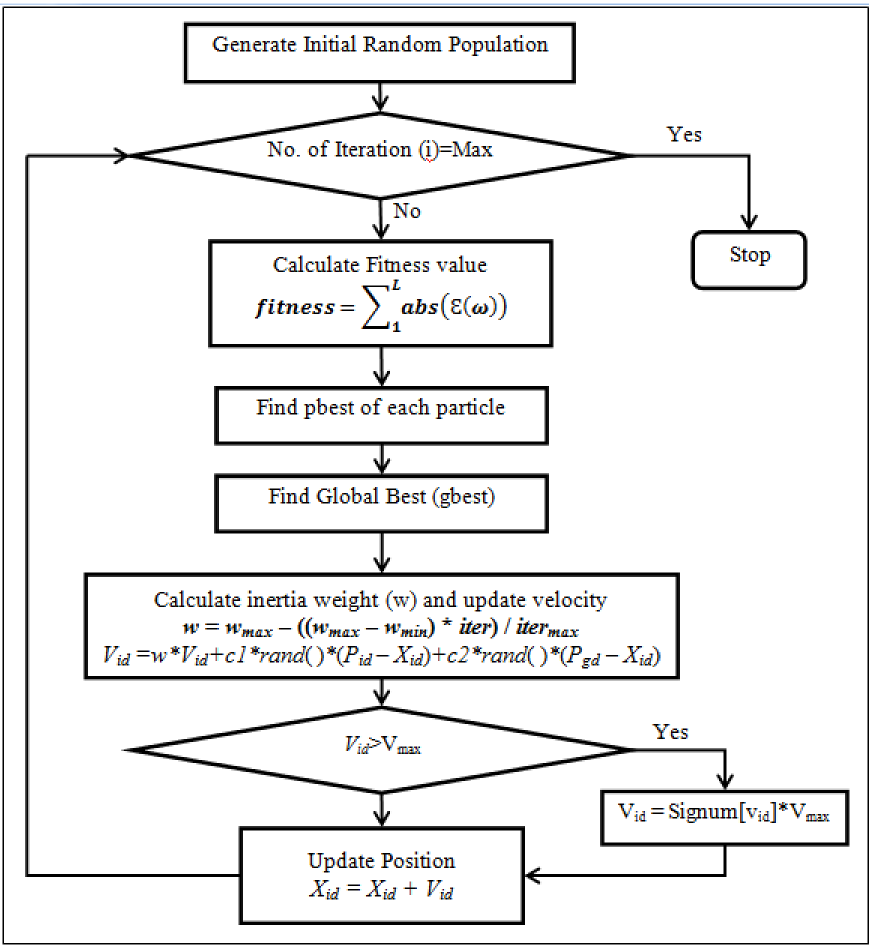

Figure2: Flow chart of the MPSO-based band pass FIR filter design.

8. RESULTS AND COMPARISION

The planned procedure of Modified Particle Swarm Optimization (MPSO) is employed for designing a 31 tap linear phase FIR bandpass filter with wc1 = 0.3π and wc2 = 0.7π. The magnitudes of the control parameters of GA, PSO and MPSO have been explained in table (1).

Table (1): Control parameters of GA, PSO and MPSO optimization algorithms.

Parameters	***GA***	***PSO***	***MPSO***
Population size	1000	1000	1000
Iteration Cycle	300	300	300
Crossover rate	0.8	-	-
Crossover	**Two Point Crossover**	-	-
Mutation rate	0.025	-	-
Mutation	**Gaussian Mutation**	-	-
Selection	RouletteWheel	-	-
Inertial weight (*w*)	-	0.8	-
w_{min}	-	-	0.6
w_{max}	-	-	0.9
V_{max}	-	-	0.5
c1	-	0.4	0.4
c2	-	0.4	0.4

Different parameters of the PSO method have been applied to show the effect of changing these parameters on the learning rate. Fig. (3) illustrates the connection involving the inertia weight (*w*) and the fitness function value. Fig. (4) illustrates the connection involving the (cognitive (*c1*) & social (*c2*)) learning parameters and the fitness function value. It is clear that the range [0.6 to 0,9] is an interesting region to select *w* from and it can be seen that the range [0.1 to 1,7] is a interesting region to decide the magnitude of *c1* and *c2* from for the linear phase FIR bandpass filter designing problem. The PSO with *w*, *c1* and *c2* in these ranges will have less chance to fail to discover the comprehensive finest FIR filter coefficients contained by a sensible iterations number and depending on these two figures, the control parameters of the

PSO method (w, $c1$ as well as $c2$) have been chosen to be (0.8, 0.4 and 0.4) respectively. Also depending on these two figures, the values of the control parameters of the MPSO method (w_{max}, w_{min}, $c1$ and $c2$) have been chosen to be (0.9, 0.6, 0.4 and 0.4) respectively.

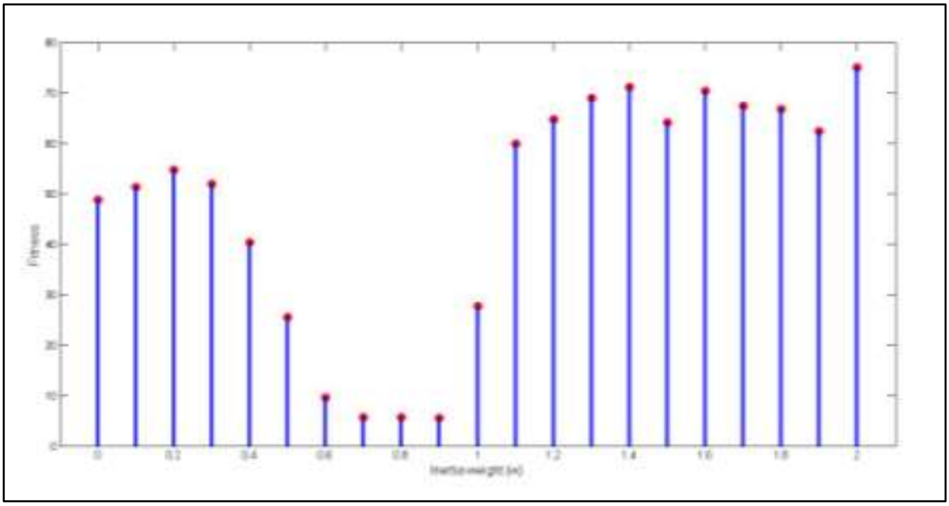

Figure 3: The fitness for different inertia weights (w).

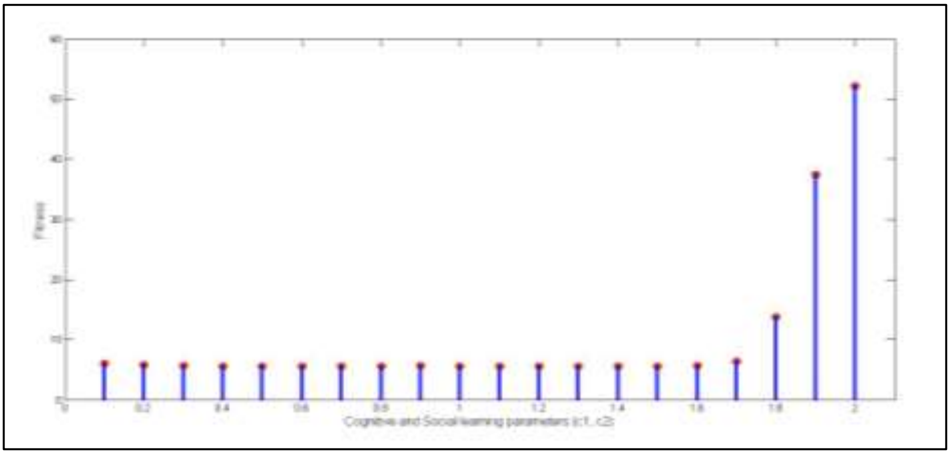

Figure 4: The fitness for different cognitive ($c1$) and social ($c2$)) learning parameters.

Figures (5, 6, 7 and 8) represent the convergence behavior, amplitude response filter coefficients &Impulse Response and magnitude & phase response of the modified particle swarm optimization (MPSO)-based 31 tap linear phase FIR bandpass filter.

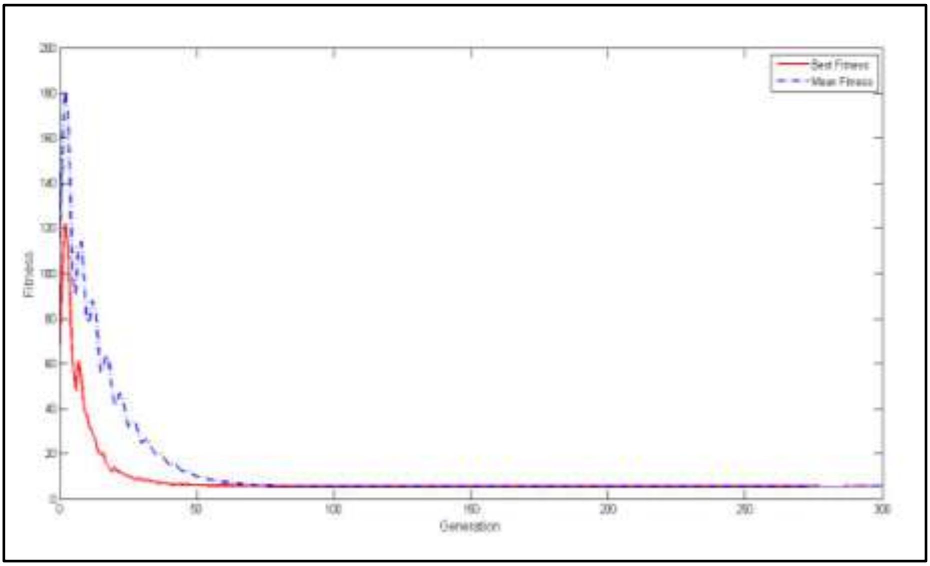

Figure 5: Convergence behaviors of MPSO in the design of the31tapBand Pass FIR filter.

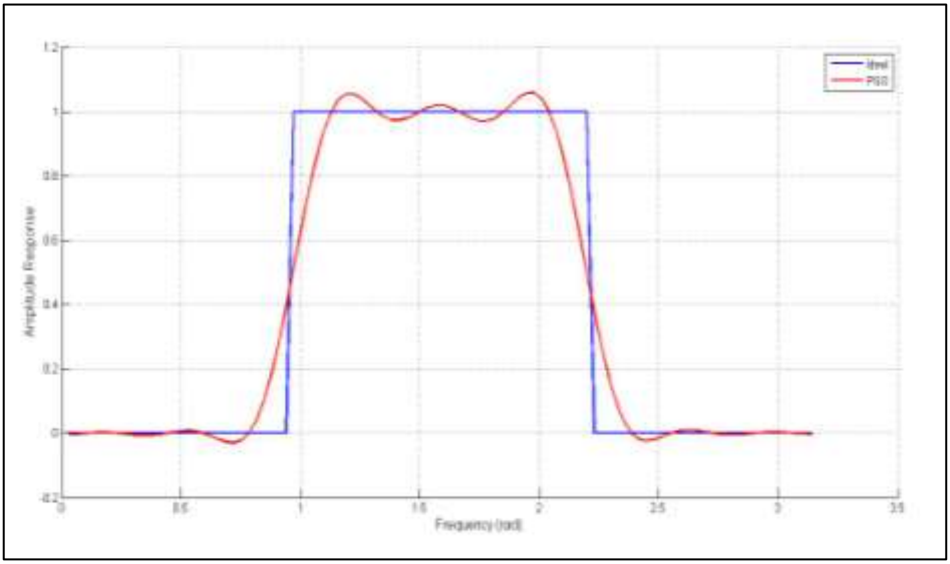

Figure 6: Amplitude Response for the31 tap MPSO-based Band Pass FIR filter.

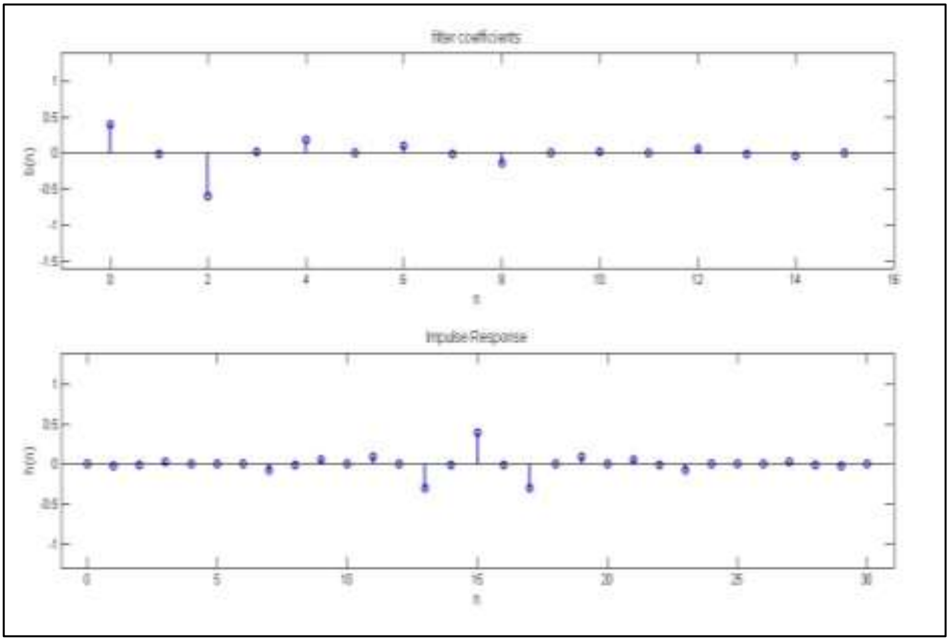

Figure 7: Filter coefficients and Impulse Response for the 31 tap MPSO-based Band Pass FIR filter.

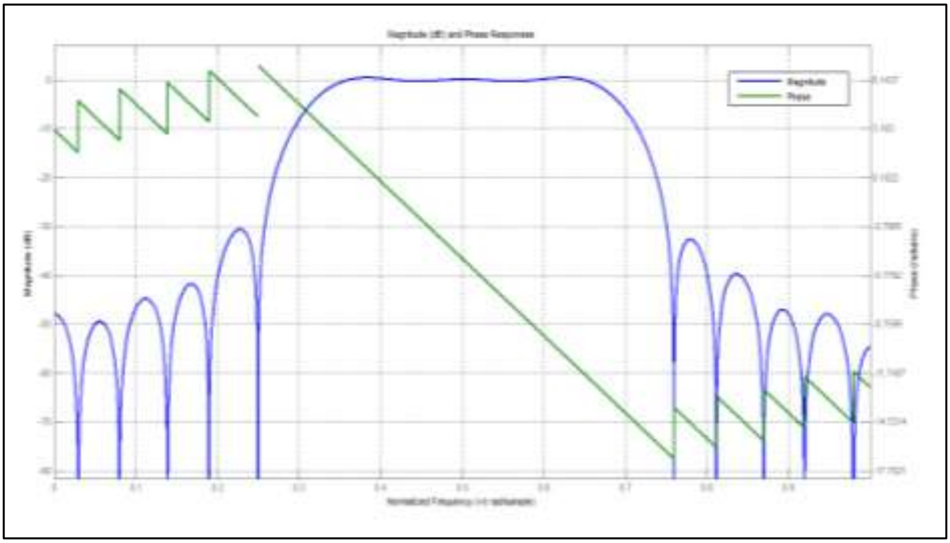

Figure 8: Magnitude and Phase Responses for the31 tap MPSO-based Band Pass FIR filter.

Fig. (9) Represents the magnitude response comparison between the MPSO method, the PSO and the conformist Genetic Algorithm (GA) based 31 tap linear phase FIR bandpass filters. By this illustration, it can be absolutely clear about the PSO advantages. The blue curve illustrates the magnitude response given by PSO. It explains superior importance response accomplished by PSO in accordance with electrical specifications of FIR filter response.

The optimal coefficients of the designed 31 tap FIR bandpass filter are evaluated by GA, PSO and MPSO algorithms are shown in table (2).

Table (2): Optimized coefficients of Band Pass FIR filter of order 30 designed using GA, PSO and MPSO optimization algorithms.

h(N)	*MPSO-based Band Pass FIR Filter coefficients*	*PSO-based Band Pass FIR Filter coefficients*	*GA-based Band Pass FIR Filter coefficients*
h(1) = h(31)	0.0016	-0.0018	-0.0019
h(2) = h(30)	-0.0167	-0.0263	-0.0117
h(3) = h(29)	-0.0045	0.0011	-0.0099
h(4) = h(28)	0.0281	0.0456	0.0306
h(5) = h(27)	0.0021	-0.0063	0.0170
h(6) = h(26)	0.0068	-0.0046	-0.0037
h(7) = h(25)	0.0049	0.0136	0.0024
h(8) = h(24)	-0.0656	-0.0687	-0.0593
h(9) = h(23)	-0.0075	-0.0165	-0.0208
h(10) = h(22)	0.0524	0.0670	0.0602
h(11) = h(21)	-1.2167e-04	0.0124	0.0040
h(12)=h(20)	0.0944	0.0795	0.0820
h(13)=h(19)	0.0086	-0.0084	0.0240
h(14)=h(18)	-0.2979	-0.2897	-0.3000
h(15)=h(17)	-0.0058	0.0036	-0.0173
h(16)	0.3943	0.3898	0.4059

Fig. (10) Shows convergence behavior of bandpass FIR filters designed by MPSO, PSO and GA with 300 test operations. It is clear that the convergence speed of MPSO is drastically enhanced under the similar iterations.

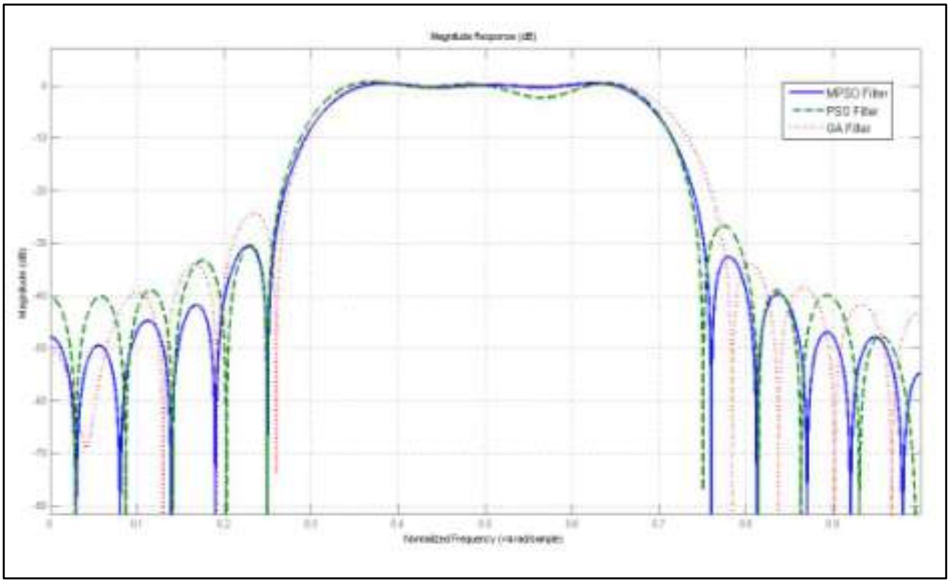

Figure 9: Magnitude Responsefor31 tap Band Pass FIR filter using MPSO, PSO, and GA.

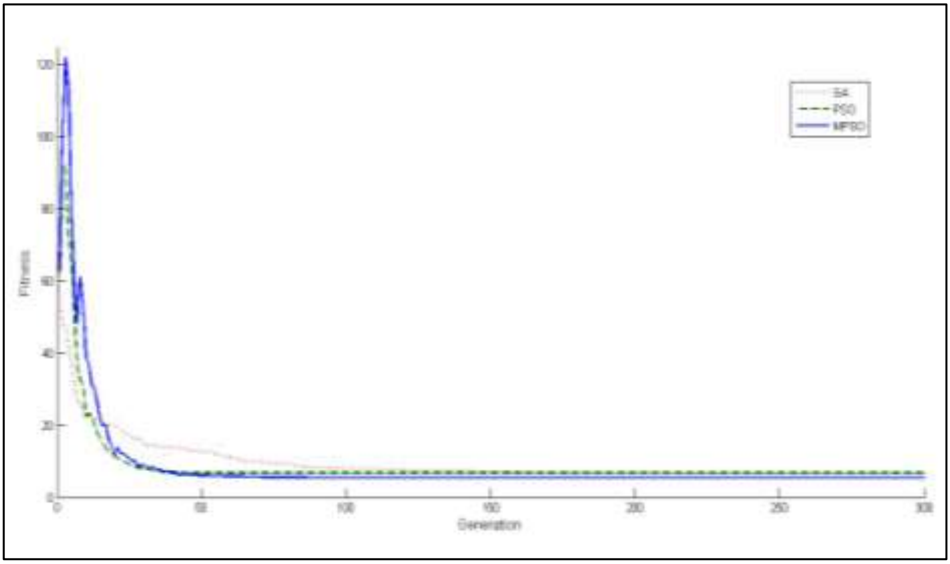

Figure 10: Convergence behavior for MPSO, PSO andGAfor31 tap Band Pass FIR filter.

9. Conclusions

Modified Particle swam optimization (MPSO) method is a developed heuristic optimizing tool derived from swarm intelligence. Compared to the other optimization methods, MPSO is uncomplicated, simply accomplished and requires less parameters. MPSO is employed for the solution of the constrained, multi-modal FIR band pass filter design problem with finest filter parameters in this paper. It is related to conventional GA and standard PSO optimizing techniques that are also swarm intelligence and population based methods like MPSO method. The suggested MPSO method do better than GA and PSO in the accurateness of the FIR band pass filter response in addition to the convergence velocity. Consequently, MPSO can be adopted as a high-quality optimizing tool for FIR ban dpass filter response.

Simulated results are shown as the impact of changing the particle swarm optimization parameters like the inertia weight (w), cognitive ($c1$)and social ($c2$) to determine the optimal control parameters of the MPSO scheme for the FIR band pass filter designing problem. It is understandable that the MPSO with the inertia weight (w) in range from 0.6 to 0.9 and the (cognitive ($c1$) & social ($c2$)) in the range [0.1 to 1.7] has generally an enhanced performance and a better possibility to discover the total finest results within a practical iterations number.

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