DESIGN OF HIGH ORDER DIGITAL IIR FILTER USING HEURISTIC OPTIMIZATION TECHNIQUE

AMANDEEP KAUR MAAN, BALRAJ SINGH AND DARSHAN S.SIDHU
GZS PTU Campus, Department of Electronics and Communication Engineering, Bathinda, India
Email: mannaman72@gmail.com, erbalrajsidhu@rediffmail.com, dssidhu@yahoo.com

ABSTRACT: The paper develops a soft computing technique to solve the problem of designing an optimal digital infinite-impulse response (IIR) filter. In this paper a nature inspired optimization methodology is proposed for the robust and stable design of high order LP digital IIR filter. Particle Swarm Optimization (PSO) technique is applied to design the optimal digital IIR filter in order to avoid local minima as the error surface of IIR filters is multi-modal and non-linear. PSO utilizes a global search method, which utilizes a set of particles that move through the hyperspace to find the global minima of the objective function. The main objective of the optimization process is to find the filter coefficients approximately close to the desired filter response. To obtain our design criterion approximation magnitude error and ripple magnitudes of both pass-band and stop-band. The magnitude response and the stability of the filter are determined by using Matlab. The pole-zero plot of the filter, describe the stability of the predesigned filter. This technique can also be used for the design of HP, BP and BS digital IIR filters.

KEYWORDS: Digital Infinite-Impulse Response (IIR) filter, Particle Swarm Optimization (PSO) algorithm, Low Pass (LP) filter, High Pass (HP) filter, Band Pass (BP) filter, Band Stop (BS) filter.

INTRODUCTION

Over the past few decades, digital signal processing has developed rapidly both theoretically and technically in the area of science and engineering. Digital signal processing is an integrated circuit, designed for manipulations of high speed data and also used in applications like audio, video communication, data-acquisition and other image processing applications. In DSP, digital means is used for the processing of signals. DSP is characterized by the representation of discrete time, discrete frequency or other discrete domain signals by a sequence of numbers or symbols. The main advantages of DSP are its applicability to very low frequency signals, easy to store and use, more efficient, less expensive and easy to configure. In signal processing, the main function of a filter is to remove unwanted parts of the signal such as random noise, prescribed frequency range components or to extract meaningful data of the signal. Filters are also basically a frequency selective circuit that allows a certain band of frequency to pass while attenuating the remaining frequencies. This divides the filters into 4 categories: i) Low Pass ii) High Pass iii) Band Pass iv) Band Stop Filters. Based on the type of input signals filters are classified as: analog filters and digital filters. Analog filters operate on continuous-time signals while digital filters operate on sampled, discrete-time signals. The use of computational power to digital signal processing allows for many advantages over analog processing in many applications such as error detection and correction in transmission as well as data compression. Analog filters have operational amplifiers, capacitors, resistors as their basic elements. However digital filters consist of DSP processors and controllers. Some of the advantages of a digital filter are its reproducible response, temperature insensitivity and programmability.

Mc-GrawHill Education
GRENZE ID: 02.PEIE.2015.6.502

Digital filters are classified into two groups: infinite impulse response (IIR) Digital Filters and finite impulse response (FIR) Digital Filters. FIR digital filter has finite duration of impulse response, whereas impulse response for IIR digital filter exists between 0 to infinity.FIR digital filters are said to be non-recursive as their output value depends on the present and past input values having linear phase response. In IIR digital filters, the output depends on the present and past input values as well as on the previous output values. Therefore known as recursive filters having feedback.IIR digital filter has improved selectivity, computational efficiency and reduced system delay as compared to that of FIR digital filter. IIR digital filters exhibit a sharp narrow frequency response for transition-band. IIR digital filter system is much more efficient and easy to implement than FIR digital filter system.

Digital IIR filters can be designed either by transformation or optimization method. In transformation technique, first analog IIR filter is designed and then converted to digital IIR filter. Basically in this approach, bilinear transformation is used for designing of IIR filter. By this transformation technique, Butterworth, Chebyshev and Elliptical functions have been designed. But these designed digital IIR filters by transformation approach are not good in stability. In optimization technique, the performance of the designed digital IIR filter is measured by mean-square error, and ripple magnitudes of both pass-band and stop-band. Various optimization methods have been developed to obtain optimal filter performances to some extent. Optimization is a technique of making something (as a design, system, or decision) fully perfect or effective as possible. The design objective could be simply to minimize the cost of production or to maximize the efficiency of production. Based on the objective functions and search space, optimization method are mainly of three types i) Direct search methods ii) Gradient based methods and iii) Nature inspired methods. Conventional gradient-based design methods get easily stuck in the local minima of error-surface, as IIR digital filters have non-linear and multimodal nature of error surface. So it is very important to deal with the efficient optimization design of digital IIR filters. The main constraints considered during designing of an optimal digital IIR filter are: i) determination of the lowest filter order ii) high filter stability iii) minimizing the ripple magnitudes (tolerances) of both pass-band and stop-band, as low as possible. So some researchers [9, 10, 11] have proposed various Genetic-algorithms based methods for designing of optimal IIR filter. These GA-based algorithms are able to optimize complex and discontinuous functions. But the results were not so impressive, as the GA technique was very much in its infancy at the time. Genetic algorithms have very slow convergence. Therefore, a new hierarchical GA (HGA)[12] was proposed to overcome these shortcomings. In this new scheme, the structure of the filter is not fixed and has the capability of designing the lowest order filter also capable of achieving an equivalent solution to the conventional GA approach. The use of the HGA for IIR filter design is practical because of the following advantages like i) LP, HP, BP and BS filters can be designed ii) the lowest order model can be obtained. iii) filter can be constructed in many forms, like cascade, parallel or lattice. Another approach to solve the problem of designing optimal digital IIR filters was proposed, known as hybrid Taguchi GA (HTGA) [13]. In this approach, the Taguchi method is inserted between crossover and mutation operations. In the crossover operations, the systematic reasoning ability of the Taguchi method was incorporated to reproduce the representative chromosomes to be the new potential offspring. Tsai et al.[14] have proposed a new integrated method named as Taguchi-immune algorithm (TIA), for the design of optimal digital IIR filter. In this, the digital IIR filter structure and its coefficients have been coded separately. TIA is more robust, statistically sound, and quickly convergent. But the standard deviation of the affinity values is relatively small.

The intent of this paper is to propose a robust particle swarm optimization (PSO) method for the design of high order Low Pass digital IIR filters. PSO was developed by Eberhart and Kennedy in 1995. This evolutionary technique is more efficient than other previously discussed techniques. This robust population based flexible optimization technique is based on social-psychological principles. Based on swarm intelligence, PSO method is based on social behaviour of bird flocking or fish schooling. It is used to optimize a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO has many advantages like i) easy to implement ii) fast convergence speed as compared to other techniques. The selection of PSO parameters is important for efficient working of PSO.

This paper is organized as: Section II describes the IIR filter design problem. Section III describes the PSO algorithm used for the designing of optimal high order Low Pass digital IIR filters. The evaluated results are compared with the results of Tang et al. [12], Ranjit Kaur et al. [3],Tasi et al. [13] in section IV. The conclusion of the proposed work is described in section V.

LITERATURE SURVEY

Kit-sang Tang, et al., [1998] have proposed a new genetic algorithm (GA) for digital filter design. This scheme utilizes a new hierarchical multilayer gene structure for the chromosome formulation. This is a unique structure, which retains the conventional genetic operations, while the genes may take various forms to represent the system characteristics. As a result, both the system structure and the parametric variables can be optimized in a simultaneous manner.

Jinn-Tsong Tsai, et al., [2006] had proposed a hybrid genetic algorithm (HTGA) to solve the problem of designing optimal digital infinite-impulse response (IIR) filters. The HTGA approach is a method of combining the traditional GA (TGA), which has a powerful global exploration capability, with the Taguchi method, which can exploit the optimum offspring. The Taguchi method is inserted between crossover and mutation operations of a TGA. Based on minimizing the -norm approximation error and minimizing the ripple magnitudes of both pass-band and stop-band, a multi-criterion combination is employed as the design criterion to obtain the optimal IIR filter.

Jyh- Horng Chou, et al., [2006] have described an improved immune algorithm which is based on both the features of a biological immune system and the systematic reasoning ability of the Taguchi method named as Taguchi immune algorithm (TIA). This algorithm is used to solve the problem of designing the optimal digital IIR filters. Their experimental results shows that the TIA approach can obtain better digital IIR filters than the genetic algorithms based method.

IIR FILTER DESIGN PROBLEM

In the optimal design of digital IIR filter, a set of filter coefficients is determined to meet the prescribed performance of pass-band width and gain, stop-band width and its attenuation, frequencies at the band edges, and value of peak ripple in the pass-band and stop-band. The design of recursive type IIR filter is described by the difference equation as:

$$y(n) = \sum_{k=0}^{N} p_k\, x(n-k) - \sum_{i=1}^{M} q_i\, y(n-i) \qquad (1)$$

where p_k and q_i are coefficients of the filter. x(n) and y(n) are the input and output of the filter respectively. N and M gives the order of the filter with M≥N. The transfer function of IIR filter is given as:

$$H(z) = \sum_{k=0}^{U} p_k z^{-k} \Big/ 1 + \sum_{i=1}^{V} q_i z^{-k} \qquad (2)$$

To meet the specified desired performance response, we need to specify a set of filter coefficients. To avoid instability, we need to realize IIR filters in cascaded form of first-order and second-order filter simultaneously. The cascaded transfer function of digital IIR filter, involving the filter coefficients like poles and zeroes, is stated as:

$$H(w, x) = A \prod_{i=1}^{M} \frac{1 + a_{1i} e^{-jw}}{1 + b_{1i} e^{-jw}} \times A \left(\prod_{k=1}^{N} \frac{1 + c_{1k} e^{-jw} + c_{2k} e^{-2jw}}{1 + d_{1k} e^{-jw} + d_{2k} e^{-2jw}} \right) \qquad (3)$$

where $x = [a_{11}, b_{11}, .., a_{1M}, b_{1M}, c_{11}, c_{21}, d_{11}, d_{21}, .. c_{1N}, c_{2N}, d_{1N}, d_{2N}, A]^T$
The vector x represents the filter coefficients of dimension V×1 with V = 2M+4N+1 and w represents the discrete frequency. In the IIR filter, the coefficients are optimized such that the approximation error function for magnitude is to be minimized. The magnitude response is specified in pass-band and stop-band at K equally spaced discrete frequency points. For optimizing the filter coefficients, L_p-norm approximation error function for magnitude is minimized. The L_p-norm approximation error $err_m(x)$ for the magnitude response is defined as:

$$err_m(x) = \left\{ \sum_{i=0}^{K} \left| H_d(w_i) - |H(w_i, x)| \right|^p \right\}^{1/p} \qquad (4)$$

where $H_d(w_i)$ is the magnitude response of the ideal IIR filter and $H(w_i, x)$ is the magnitude response of the desired IIR filter. For p = 1, the magnitude response error denotes the L_1 – norm error and is defined as:

$$err_m(x) = \sum_{i=0}^{K} \left| H_d(w_i) - |H(w_i, x)| \right| \qquad (5)$$

Ideal magnitude response $H_I(w_i)$ of IIR filter is given as:

$$H_d(w_i = \begin{cases} 1, \text{for } w_i \epsilon \text{ passband} \\ 0, \text{for } w_i \epsilon \text{ stopband} \end{cases} \qquad (6)$$

$e_1(x)$ and $e_2(x)$ are the ripple magnitudes of pass-band and stop-band, respectively. We have to minimize $e_1(x)$ and $e_2(x)$ respectively as:

$$e_1(x) = \max_{w_i} |H(w_i, x)| - \min_{w_i} |H(w_i, x)| \quad \text{for } w_i \epsilon \text{ passband} \qquad (7)$$

$$e_2(x) = \max_{w_i} |H(w_i, x)| \quad \text{for } w_i \epsilon \text{ stopband} \qquad (8)$$

Minimize $g_1(x) = e_1(x)$ and $g_2(x) = e_2(x)$ (9)

The stability constraints which are obtained by aggregating all objectives and stability constraints for optimization are:

$1 + b_{1i} \geq 0$ (i =1, 2,….,M)
(10)
$1 - b_{1i} \geq 0$ (i =1, 2,…., M)
$1 - d_{2k} \geq 0$ (k = 1, 2, …., N)
$1 + d_{1k} + d_{2k} \geq 0$ (k = 1, 2,…., N)
$1 - d_{1k} + d_{2k} \geq 0$ (k = 1, 2,…., N)

PARTICLE SWARM OPTIMIZATION

PSO is an evolutionary computation technique developed by Eberhart and Kennedy in 1995, inspired by the social behaviour of bird flocking and fish schooling. PSO has capability to handle non-differential objective function and larger search space; therefore used for problem solving method in engineering and computer science. In this approach, particles are randomly set into motion that fly the problem hyperspace with given velocities. At each iteration, the velocities of the individual particles are stochastically adjusted according to the historical best position for the particle itself and the neighbourhood best position. PSO is a computational intelligence, naturally-inspired technique that is not largely affected by the size and non-linearity of the problem. This approach can converge to the optimal solution in many problems where most analytical methods fail to converge. PSO technique has many advantages like: i) easy to implement. ii) fewer parameters to adjust. iii) fast computation. iv) robust search ability. v) In PSO every particle remembers its own previous best value as well as the neighbourhood best. So it has more effective memory capability than the GA.

In the optimal design of IIR digital filter, the efficiency and capability of PSO in the minimization of multimodal functions with many local and global minima has been verified. In this global optimization technique, each particle flies through the search space of solutions. For optimization, every particle is updated by its own best value (p best) and the global best value (g best). Now each particle modifies its position using the following points: i) the distance between the current position and the p best. ii) the distance between the current position and the g best.

$$v_f = w * C_1 + 2 * \text{rand}() * (\text{p best} - x_i) + C_2 * \text{rand}() * (\text{g best} - x_i) \tag{11}$$

$$x_f = x_i + v_f \tag{12}$$

where,
w is the weight with $w_{max} = 0.4$ and $w_{min} = 0.1$.
v_f is the final velocity of particle.
x_i is the current position of particle and x_f is the final position of particle.
p best and g best are the local best and global best of the particle.
rand () is a random value between (0, 1).
C_1 and C_2 are learning factors usually having value 2.

Algorithm for Particle Swarm Optimization

1. Initialize the swarm as initial population where each particle in swarm is a solution vector.
2. Evaluate the fitness function of each particle.
3. Compare each particle's fitness with the current particle's to obtain p best.
4. Now to obtain g best compare fitness evolution with the population's overall previous best.
5. Finally the position and velocity of each particle is updated using the equations (11) and (12).

DESIGN OF HIGH ORDER LOW PASS IIR FILTER AND DESIGN COMPARISONS

For the comparison of designing High Order digital IIR filters, firstly the lowest order is set exactly same as that given by Kaur Ranjit et al. [3], Tang et al. [12], Tsai et al. [13], then for high order the value of M & N varies from (1, 1) to (5, 5). Therefore the order of the IIR filter has been varied from 3 to 15. The purpose of designing high order Low Pass IIR digital filter is to minimize the function given by equation (9). The prescribed design conditions for the design of High Order Low Pass IIR filter are stated as below in Table 1[6]:

Table 1: Desired Design Conditions for Low-Pass filter [6]

Filter Type	Pass-band	Stop-band	$\|H(w, x)\|$
Low-Pass	$0 \leq w \leq 0.2\,\pi$	$0.3\,\pi \leq w \leq \pi$	1

The designing of high order Low Pass IIR digital filter is done by setting 200 equally spaced points within the frequency domain $[0, \pi]$. The IIR digital filter models for 3rd and 13th order filter are expressed as:

1. The designed model obtained for 3rd order LP digital filter is:

$$H_{LP}(z) = .028775\left(\frac{z+.999936}{z-.667566}\right)\left(\frac{z^2-.227070z+1.001952}{z^2-1.429517z+.731622}\right)$$

2. The designed model obtained for 13th order LP digital filter is:

$$H_{LP}(z) = 000260\left(\frac{z+.656270}{z-.357430}\right)\left(\frac{z+1.119910}{z-.394340}\right)\left(\frac{z-.381330}{z-.288040}\right)\left(\frac{z+.173470}{z+.268756}\right)\left(\frac{z-.139976}{z-.620436}\right)\left(\frac{z^2-.868500z+1.087118}{z^2-1.324383z+.764529}\right)$$
$$\times\left(\frac{z^2+.051315z+.945630}{z^2-.837166z+.309090}\right)\left(\frac{z^2-.507124z+1.553246}{z^2-1.302535z+.527182}\right)\left(\frac{z^2-.369180z+.351913}{z^2-1.367499z+.815087}\right)$$

The results obtained by PSO technique for high order Low Pass IIR filter are given in Table 2. It can be seen that the magnitude error and pass-band & stop-band ripples decreases as the order of IIR digital filter increases. This can be shown by plotting the magnitude response graph between the normalized frequency and the magnitude. For the stability of digital filters, the poles should lie within the unit circle, whereas zeroes can be anywhere. The magnitude response for 3rd order LP IIR filter and 13th order LP IIR filter is given in Fig 1 and Fig 2.

The pole-zero plots for 3rd and 13th order LP IIR filters are shown in Fig 3 and Fig 4. The filters are stable as the poles lie within the unit circle. The comparison of results obtained by PSO method for 3rd order low pass digital IIR Filter with other optimization technique's results are shown in Table 3.

The graph in between number of iterations and magnitude for 3rd and 13th order LP IIR filter is shown in Fig 5 and Fig 6. The magnitude gets stabilized after the best minimum result iteration.

The maximum, minimum, average and standard deviation in magnitude error achieved after 200 number of runs for each filter varying values of (M ,N) from (1,1) to (5,5), filter order varying from 3 to 15 is shown in Table 4. The value of standard deviation less than 1 shows that all the IIR digital filters are stable.

Table 2: Design Results for high order Low Pass IIR filter

Filter Order	**Magnitude Error**	**Pass-band Performance (Ripple Magnitude)**	**Stop-band Performance (Ripple Magnitude)**
3	3.276410	$0.78636 \leq \lvert H(e^{jw}) \rvert \leq 1.0375$ (0.251196)	$\lvert H(e^{jw}) \rvert \leq 0.1287$ (0.1287)
4	2.093997	$0.91193 \leq \lvert H(e^{jw}) \rvert \leq 1.0523$ (0.140423)	$\lvert H(e^{jw}) \rvert \leq 0.0991$ (0.0991)
5	0.470661	$0.97890 \leq \lvert H(e^{jw}) \rvert \leq 1.0086$ (0.029796)	$\lvert H(e^{jw}) \rvert \leq 0.0320$ (0.0320)
6	0.244725	$0.98368 \leq \lvert H(e^{jw}) \rvert \leq 1.0049$ (0.021252)	$\lvert H(e^{jw}) \rvert \leq 0.0098$ (0.0098)
7	0.251547	$0.99402 \leq \lvert H(e^{jw}) \rvert \leq 1.0060$ (0.011982)	$\lvert H(e^{jw}) \rvert \leq 0.0264$ (0.0264)
8	0.338020	$0.99698 \leq \lvert H(e^{jw}) \rvert \leq 1.0027$ (0.005789)	$\lvert H(e^{jw}) \rvert \leq 0.03528$ (0.03528)
9	0.153872	$0.97535 \leq \lvert H(e^{jw}) \rvert \leq 1.0084$ (0.033070)	$\lvert H(e^{jw}) \rvert \leq 0.0067$ (0.0067)
10	0.236514	$0.98412 \leq \lvert H(e^{jw}) \rvert \leq 1.0019$ (0.017804)	$\lvert H(e^{jw}) \rvert \leq 0.0213$ (0.0213)
11	0.129110	$0.99523 \leq \lvert H(e^{jw}) \rvert \leq 1.0030$ (0.007795)	$\lvert H(e^{jw}) \rvert \leq 0.0135$ (0.0135)
12	0.153186	$0.99511 \leq \lvert H(e^{jw}) \rvert \leq 1.0039$ (0.008847)	$\lvert H(e^{jw}) \rvert \leq 0.0211$ (0.0211)
13	0.102182	$0.99334 \leq \lvert H(e^{jw}) \rvert \leq 1.0055$ (0.012253)	$\lvert H(e^{jw}) \rvert \leq 0.0096$ (0.0096)
14	0.272214	$0.99448 \leq \lvert H(e^{jw}) \rvert \leq 1.0024$ (0.007962)	$\lvert H(e^{jw}) \rvert \leq 0.0103$ (0.0103)
15	0.190526	$0.99380 \leq \lvert H(e^{jw}) \rvert \leq 1.0039$ (0.010163)	$\lvert H(e^{jw}) \rvert \leq 0.0211$ (0.0211)

Table 3: Comparison of Low Pass IIR filter Results

Method	**Magnitude error**	**Pass-band Performance (Ripple Magnitude)**	**Stop-band Performance (Ripple Magnitude)**
PSO	3.2764	$0.78636\leq\|H(e^{jw})\|\leq1.0375$ (0.251196)	$\|H(e^{jw})\|\leq0.1287$ (0.1287)
RCGA	4.0095	$0.9335\leq\|H(e^{jw})\|\leq1.016$ (0.0825)	$\|H(e^{jw})\|\leq0.1510$ (0.1510)
HTGA	4.2511	$0.8914\leq\|H(e^{jw})\|\leq1.000$ (0.1086)	$\|H(e^{jw})\|\leq0.1247$ (0.1247)
HGA	4.3395	$0.8870\leq\|H(e^{jw})\|\leq1.000$ (0.1139)	$\|H(e^{jw})\|\leq0.1802$ (0.1802)

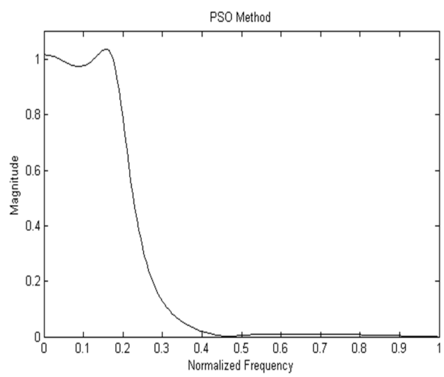

Fig 1: Magnitude Response for 3rd order LP IIR filter

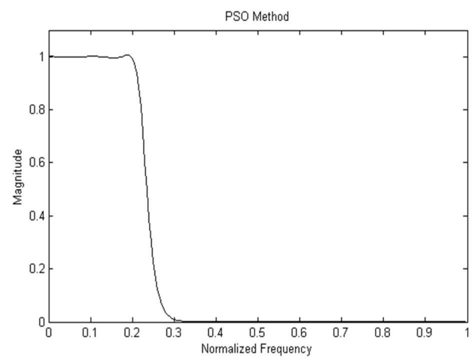

Fig 2: Magnitude Response for 13th order LP IIR filter

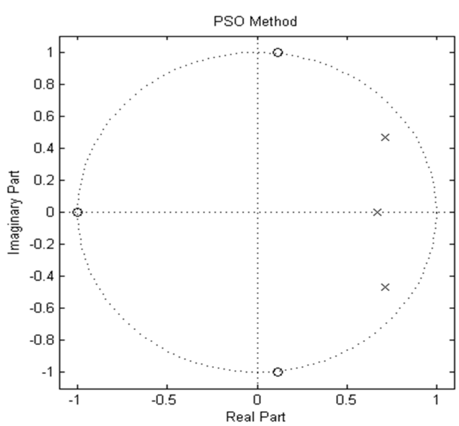

Fig 3: Pole zero plot for 3rd order LP IIR filter

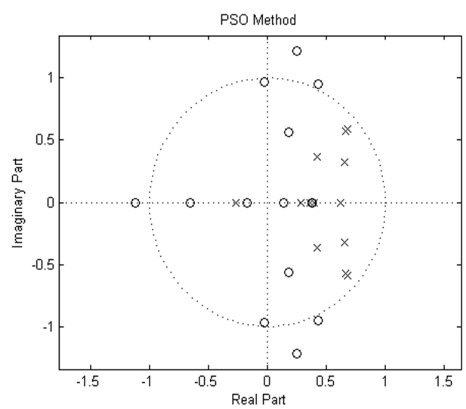

Fig 4: Pole zero plot for 13th order LP IIR filter

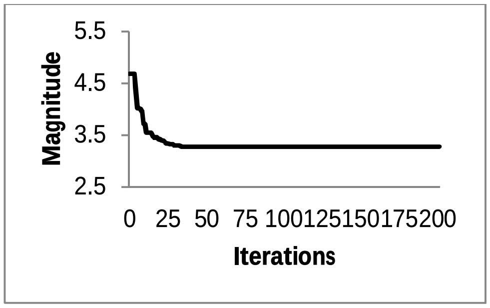

Fig 5: Iterations Vs Magnitude for 3rd order LP IIR filter

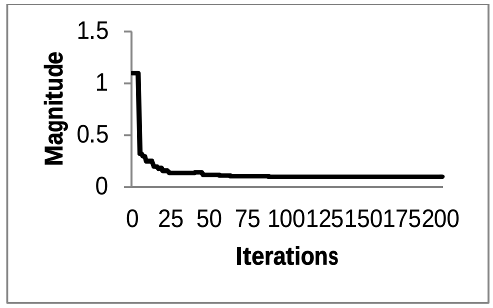

Fig 6: Iterations Vs Magnitude for 13th order LP IIR filter

Table 4: Maximum, Minimum, Average and Standard Deviation of Magnitude Error

Filter Order	Maximum	Minimum	Average	Standard Deviation
3	4.82852	3.27641	3.444347	0.199016
4	4.71647	2.09400	2.323737	0.320150
5	5.38941	0.47066	1.350028	0.856830
6	1.347546	0.24472	0.626247	0.333374
7	3.00784	0.25155	0.808703	0.449836
8	1.70624	0.33802	0.803998	0.405513
9	1.48497	0.15387	0.349397	0.232025
10	3.10898	0.23651	0.818214	0.993089
11	3.66990	0.12911	0.401264	0.384453
12	3.59037	0.15319	0.544208	0.319723
13	1.10222	0.12021	0.562724	0.480991
14	1.222907	0.27221	0.524710	0.215474
15	3.05428	0.19053	0.609116	0.945553

CONCLUSION

This paper proposes PSO method for the design of high order Low Pass stable digital IIR filter. The order of the filter has been varied from 3 to 15 by varying the values of M & N from (1, 1) to (5, 5). As shown through simulation results, the results shown by PSO are better than that of RCGA and HTGA in terms of magnitude error and ripple magnitudes in pass-band and stop-band. All the designed LP stable IIR digital filters are stable as the poles of all the filters lie within the unit circle. The best results for high order filter are of 13th order filter. So PSO algorithm has better performance over others in terms of magnitude response, convergence speed and stability for the design of high order Low Pass digital filters.

REFERENCES

John G. Proakis and Dimitris G.Manolakis,"Digital Signal Processing",Pearson,fourth edition, 2013.

Ying-ping Chen and Pei Jiang," Analysis of Particle Interaction in Particle Swarm Optimization", ELSEVIER, Theoretical Computer Science, 411, 2010.

Ranjit Kaur, Manjeet Singh Patterh, J.S. Dhillon, "Digital IIR Filter Design using Real Coded Genetic Algorithm," *I.J. Information Technology and Computer Science*, pp. 27-35, June 2013.

Y. Wang, B. Li, Y.B. Chen, Digital IIR filter design using multi-objective optimization evolutionary algorithm, *Applied Soft Computing Journal* (2010).

Suman Kumar Saha, Rajib Kar, Durbadal Mandal, S.P. Ghoshal." IIR Filter design with Craziness based Particle Swarm Optimization Technique" *International Science Index* Vol:5, No:12,2011.

Jinn-Tsong Tsai, Jyh-Horng Chou and Tung-Kuan Liu, "Optimal design of digital IIR filters by using Hybrid Taguchi Genetic Algorithm" *IEEE Transactions on Industrial Electronics*, Vol. 53, No. 3, pp. 867–879, June 2006.

Subhadeep Chakraborty, Abhirup Patra, "Performance Analysis of IIR Digital Band Stop Filter," International Journal of Advanced Research in Computer Engineering & Technology *(IJARCET)*, Volume 2, No 5, May 2013.

Balraj Singh, J.S. Dhillon, Y.S.Brar," A Hybrid Differential Evolution Method for the Design of IIR Digital Filter." ACEEE International Journal on Signal & Image Processing, Vol.4, No.1, Jan 2013.

S.C.Ng, C.Y.Chung, S.H.Leung, and A.Luk,"Fast convergent genetic search for adaptive IIR filtering", in Proc.IEEE Int.Conf.Acoust.,SpeechSignalProcess.,Adelaide,Australia,1994,pp.105-108.

J.H. Li and F.L. Yin, Genetic optimization algorithm for designing IIR digital filters, Journal of China Institute of Communications, vol**.** 17, pp. 1–7, 1996.

J.M. Renders and S.P. Flasse, Hybrid methods using genetic algorithms for global optimization, IEEE Transactions on Systems, Man, and Cybernetics-Part B: vol. 26, no. 2, pp. 243-258, April 1996.

Kit-sang Tang, Kim-fung Man, Sam Kwong and Zhi-feng Liu, "Design and Optimization of IIR Filter Structure Using Hierarchical Genetic Algorithms," *Ieee Transactions on Industrial Electronics*, vol. 45, no. 3, June 1998.

Jinn-Tsong Tsai, Jyh-Horng Chou and Tung-Kuan Liu "Optimal Design of Digital IIR Filters by Using Hybrid Taguchi Genetic Algorithm," *IEEE Transactions on Industrial Electronics*, vol. 53, no. 3, June 2006.

Jinn-Tsong Tsai and Jyh-Horng Chou "Design of Optimal Digital IIR Filters by Using an Improved Immune Algorithm," *IEEE Transactions on Signal Processing*, vol. 54, no. 12, December 2006.

MATLAB User"s Guide, *The MathWorks*, Inc., Natick, MA, 1991.