Different Design Approaches for the Optimization of FIR Filter Coefficients

Supreet Kaur [1], Butta Singh[2] and Manjit Singh[3]
Electronics and Communication Engineering Department
Guru Nanak Dev University
Regional Campus, Jalandhar
Email: [1]Kaursupreet48@gmail.com,[2] bsl.khanna@gmail.com and [3] manu_kml@yahoo.co.in

Abstract. A digital filter is a system that uses discrete time signal as input and produce a discrete time output signal for the purpose of achieving a filter objective. Parks-McClellan method provides optimum equiripple approximation to the desired frequency response and has become the dominant method for optimum design of FIR filters. The filter design process can be described as an optimization problem where each requirement contributes with the term to an error function which should be minimized. This paper deals with the various optimization methods and approaches applied for linear phase FIR filtering. A brief performance comparison of these techniques is also performed.

Keywords: optimization, Particle swarm optimization (PSO), Real genetic algorithm (RGA), Cat swarm optimization (CSO), Steepest descent optimization algorithm, Differential evolution algorithm (DE)

1. INTRODUCTION

An important trend that has been a major issue of the electronics industry in the recent years is the growing demand of portable computing and communication devices [1]. A portable multimedia terminal must provide two fundamental capabilities; the ability to process multimedia information and the ability to communicate that information through various wires and/or wireless communication channels. The technology that provides the underlying algorithms to process these types of data is digital signal processing (DSP). DSP is one of the fastest growing fields in modern electronics. It is being used in all areas where information is handled in digital form or controlled by digital processor. Now very efficient and powerful DSP processors are available for various DSP tasks such as digital filtering, linear convolution, circular convolution etc.

Filters are frequently used in signal processing by virtue of easy implementation and stability. In signal processing, the function of filters is to remove unwanted parts of the signals, such as random noise, or to extract useful parts of the signal, such as the components lying within a certain frequency range [1]. There are mainly two kinds of filters, analog filter and digital filter.

Digital filtering is one of most important tool of DSP. Digital filtering are capable of performing that specification that are extremely difficult, to achieve with analog implementation [2, 3]. In addition the characteristics of digital filtering can easily be changed under software control. Two types of filtering provide these functions finite impulse response (FIR) and infinite impulse response (IIR). FIR filtering is considered better as compared with IIR filtering as; recursive; linear phase; stability.

FIR filter designing is basically categorized into two parts; approximation problem & realization problem. Traditionally, digital filters applications has limited to audio and high-end image processing. With the modification in the methodologies in digital filtering they are very cost effective in IF range. Digital filtering are basically used in audio frequencies as it provides accuracy and the cost is very much low as a compared with analog systems. Vital research works in the recent years in designing of digital filters are taken into account. The two important uses of filters are: signal restoration and signal separation. Signal restoration is needed when there is distortion in the signal in some way. Signal separation is required when the interference, noise or other signals are mixed with the required signal. An Impulse response, a step response and a frequency response are main characteristics of linear filter. Each of these responses contains the whole information about the filter, but the formation is different.

1.1 Linear phase optimization and power consumption in FIR digital filter

"Linear phase" refers to the condition where the phase response of the filter is a linear (straight-line) function of frequency (excluding phase wraps at +/- 180 degrees). A FIR filter is linear phase if its coefficients are symmetrical around the centre coefficients that are the first coefficients same as compared with last coefficient and the second coefficient is same as the next to last coefficient. So in order to obtain this linear phase various algorithms has been discussed. The accurate control on the various frequency spectrums is the main objective function for the designing of optimal digital filters which is highly non-linear, non-uniform, non-differentiable and multimodal in nature. These objectives functions are cannot be optimized by classical optimization methods and are not converge to the global minimum solution. In order to reduce all these drawbacks which are encountered with the classical optimization approaches, several researchers have used many heuristic and meta-heuristic evolutionary optimization methods in which the majority are related to the evolutionary and natural techniques. These include Genetic algorithm (GA) [4], Differential algorithm (DE) [5, 6], Simulated annealing algorithm [7, 8], Bee colony optimization [9], artificial neural networks [10], and Collective animal behaviour (CAB) [11].

The second major problem associated with the increases in the processing power and the sophistication of signal processing algorithms is the increasing levels of power dissipation [6]. Two kinds of power dissipation takes place – static dissipation; due to leakage current or other current from the power supply & dynamic dissipation; due to switching transient current. The multiplication and accumulation of filter coefficients with the input digital data are the core operations of the FIR filters and those which can be realized using as many adders and multipliers as the numbers of filters coefficients, respectively. As multipliers are power and area consuming circuits, so the use of multiplier less realization is in common practise where the multipliers are replaced with adders and shift registers. The goal of optimization approach is to minimize the difference between the achieved and desired frequency magnitude response and to modify the filter coefficients. The optimization algorithm are many as; simulated annealing [12], hybrid genetic algorithm [13], discrete-filled functions [4], polynomial-time algorithm [14], mixed integer line programming [5] and others [6] have been successful. However they has some drawback that one or more design parameters, like-the filter length, the number of SPoT terms and filters taps are fixed in the design process. This disadvantage leads to greater design complexity in filter designing than necessary.

In this paper an attempt is made to explore the various optimization techniques of linear phase and power consumption optimization.

2. OPTIMAZATION TECHNIQUES FOR DIGITAL FIR FILTER

2.1 Real coded genetic algorithm (RGA)

In RGA, firstly initialize the real chromosomes string vectors of n_p population. Each vector string consists of $(n/2+1)$ numbers of $h(n)$ coefficients for Nth order FIR filter design. The steps of RGA as adopted from [15, 16] and are used for the implementation process as under:

Step 1: Firstly initialize the vector string (within bounds -2 and +2).

Step 2: Evaluation of the error fitness of each string vector. *(H): Fitness=1/abs (ε(ω))*

Step 3: Make the selection of sting so that it increases the error fitness value from the minimum value.

Step 4: Now copying the strings over the strings which are not selected.

Step 5: Crossover and mutation generate the off-spring.

Step 6: Genetic cycle updating and iteration repeats from step 2.

The iteration process stops when the maximum number of iteration cycles reached. The minimum error fitness, optimal filter coefficients and $(n+1)$ number of filter coefficients are finally obtained by copying and concatenating the filter coefficients in order to get the final optimal frequency spectrum of the FIR filter.

2.2 Steepest descent optimization algorithm

This algorithm was proposed by Joaquim and Lucietto in 2011 [17, 18]. Basically it minimizes the mean square error between the desired frequency response and the frequency response of the approximation. The advantage of this algorithm is that there is no need to select the filter order in advance. In case any error occurs the algorithm increases the filter order. Given the desired frequency response, $H_d(e^{jw})$ and a maximum approximation error δ, the proposed algorithm for the steepest-descent method adjust the weights *h(n)*is

Step 1: Initialization: guess an estimate for M where it defines the filter coefficient and *h(n)*;

Step 2: Choose the step size μ where the maximum value of size μ is

$$\frac{\mu \le 2}{1+2M}$$

Step 3: Search the maximum absolute error in frequency band;

Step 4: If absolute error $\left|\in^{i+1}(w_k)\right|$ is less than δ, stop the approximation.

Step 5: If error is not less than δ, increase M by one, i.e, set a new column which has zero value in the last estimate of *h(n)* and go to step 3;

Step 6: Else if the error is more thanδ, calculate the new filter coefficient using the equation

$$h^{i+1}(n) = h^i(n) - \mu \in (w_k)\cos(w_k n)$$

Where n = 0,1,2.......,M,

Step 7: Go to step3.

The algorithm is very simple, produces acceptable digital FIR filters, presents less errors and can easily be implemented on digital computers.

2.3 Particle swarm optimization (PSO)

The study of the simple model of the bird and the behaviour of the bird and its simulation. Similar steps for PSO as [19] are implemented for the optimization of filter coefficients *h(n):*

Step1: Initialization: population of particle vectors $n_p=50$; maximum iteration cycle=500; filter order=*nvar=20;(nvar/2+1)*number of coefficients *h(n).*

Step 2: Generation of initial particle vectors of filter coefficients *(nvar/2+1*) randomly with limits.

Step 3: Computation of the initial personal best solution vectors ($_p best$) and the group best solution ($_g best$).

Step 4: Updating the velocities and particle vectors by the following equations:

$$v_i^{(k+1)} = w * v_i^k + c_1 * rand_1 * ({}_p best_i^k - s_i^k) + c_2 * rand_2 * ({}_g best^k - s_i^k)$$

$$s_i^{(k+1)} = s_i^k + v_i^{(k+1)}$$

Step 5: Updating of the $_g best$ and $_p best$ on the basis of the fitness values.

Step 6: Iteration continues from step 4 till the maximum number of cycles is reached.

Step7: Finally, *hgbest* is the vector of the optimal filter coefficients *(nvar/2+1).* Now copying and concatenating the complete *nvar* coefficients in order to obtain the optimal frequency response.

PSO approach is flexible, robust and population based stochastic search and can easily be handled with non – differential objective functions of digital filters. This is the best method of the optimization.

2.4 Differential evolution algorithm

The DE algorithm was first introduced by Storn and Price in 1995 [20, 21]. The idea behind this algorithm is a method for generating trial parameter vectors and adds the weighted difference between two population vectors to a third one. As every other algorithm objective is to evolving a population of n_p, D-dimensional parameter vectors , so called individuals, that helps in encoding the candidate solution, i.e.,

$x_{i,g} = \{x_{1,i,g}, x_{2,i,g}, ...x_{Di,g}\}$,

Where i=1,2,3....,n_p.

Following step are performed for the implementation of DE algorithm:

Step 1: Firstly initialization of all the individual of n_p population takes places randomly every population consists of *(N/2+1)* number of *h(n)* coefficients.

Step 2: Mutation: *for i=1 to n_p*, generate a mutated vector, $v_{i,g}=\{v_{i,g}, v_{2,g}...v_{d,g}\}$ corresponding to the target vectors $x_{i,g}$ by the equation given below, the best value of F determined in this work equals to 0.5.

$$"DE/rand-to-best/1": \vec{v}_{i,g} = \vec{x}_{i,g} + F(\vec{x}_{best,g-}\vec{x}_{i,g}) + F(\vec{x}_{r1,g} - \vec{x}_{r2,g})$$

Step 3: Crossover: Generate a trial vector $u_{i,g}$ for each target vector $x_{i,g}$ where $u_{i,g}=\{u_{1,g}, u_{2,g}....u_{d,g}\}$ as follows:

For $i=1$ *to* n_p; $j_{rand}=\{rand(0,1)*D\}$;for j=1toD.

$$u_{j,i,g} = \begin{cases} v_{j,i,g} if\,(rand_{i,j})(0,1) \le c_r \\ x_{i,j,g} otherwise \end{cases}$$

End

Step 4: Selection:

For *i=1 to n_p*

$$\vec{x}_{i,g+1} = \begin{cases} \vec{u}_{i,g} if\,(f(\vec{u}_{i,g}) \le f(\vec{x}_{i,g}) \\ \vec{x}_{i,g} otherwise \end{cases}$$

End

Step 5: Increment the generation count $g=g+1$. The generation cycle repeats from step 2 till the maximum number of generation cycle is reached.

This algorithm is most reliable and effective is order to get the optimal linear response of FIR filter. Hence the power dissipation can also be eliminated.

2.5 Cat Swarm Optimization (CSO)

CSO optimization is also called as meta-heuristic evolutionary algorithm [22, 23, 24]. The algorithm initiates the behaviours of cats. As we already know the cat has a strong curiosity towards moving objects and posses good hunting skills. The two most important characteristics of cats are (1) resting with slow movements (2) chasing with high speed are represented by seeking and target modes. Following steps are used for implementing this algorithm:

Step 1: Create *N* number of cats in process.

Step 2: Randomly sprinkle the cats into the *D (=N/2+1)* number of *h(n)* coefficients Bounded between (-2,+2). Randomly give them values between (-0.1, 0.1). Now randomly pick the cat and placed them in tracing mode as per there MR value and put rest of them in seeking mode.

Step 3: Evaluate the fitness function of each cat and then keep the best cat into the memory. Remember only the best cat gives the best solution. *(H): Fitness=1/abs (ε(ω))*

Step 4: Move the cats according to their flags, if cat_i is in the seeking mode place then in the seeking section otherwise apply it in the tracing section

Step 5: Re-pick the cats again and place them into tracing mode and put rest of the cats into the seeking mode.

The grand minimum error fitness its corresponding optimal cat having *(N/2+1)* number of coefficients *h(n)* is determined. Finally total optimal coefficient equal to *(N+1)* is obtained by concatenating &copying the above coefficients. So that we can get final optimal frequency spectrum of FIR filter.

2.6 Stimulated Annealing Algorithm

The simulated annealing (SA) optimization algorithm is basically based on an analogy between the behaviours of a solid which is melted and than that is slowly cooled (annealed) into a “perfect" crystal. The algorithm, works together with genetic and neural network algorithms, belongs to a group of algorithms sometimes they are also called as “natural" algorithms since they rely on observations made in the study of natural systems such as the forming of crystals, the evolution of the species, and the workings of the human brain. [25, 26]

A noteworthy point about the annealing process is that any single atom in the system only interacts (strongly) with its local neighbours and has no knowledge of the energy of the system as a whole, but under suitable surrounding conditions still arranges themselves in an optimal configuration with respect to the global energy of the system. To formulate an optimization algorithm based on the observations, a state of the forming solid would correspond to a possible solution to the optimization problem and the energy of that state would correspond to the quality, or cost, of that solution. [27]

SA algorithm is beneficial for arbitrary system moreover is cost function is quite acceptable. But it has one drawback also that it is very time consuming process for the complex cost functions. Table 1: Shows the comparison of different approaches in literature of linear phase FIR filter optimization. The CSO based approach for 20th order LP filter design results in 33.99db stop band attenuation, maximum pass band ripple (normalized)=0.164, maximum stop band ripple(normalized)=0.01998, transition width=0.0946. The simulation results of Sarangi et al. [29] show that for the LP filter of order 20, the maximum stop band attenuation (db) is less than 27db (approx.), maximum pass band ripple (normalized) is more than 0.1, maximum stop band ripple (normalized) is more than 0.06,transition width is more than 0.15. The simulation results obtained for the HP filter using CSO are as follows: 33.62 db stop band attenuation, maximum pass band ripple (normalized)=0.132, maximum stop bad ripple(normalized)=0.0285, transition with=0.0941. The CSO optimized BP of order 20 results in 34.47 db stop band attenuation, maximum pass band ripple (normalized)=0.163, maximum stop band ripple (normalized)=0.01891, transition width=0.1006. From the table, it is observed that the simulation results obtained for filter order 20 using the CSO are showing the better performance than the other reported results.

Table1. Performance comparison of available techniques

Model	**Filter type**	**Order**	**Maximum stop band attenuation (db)**	**Maximum pass band ripple (normalized)**	**Maximum stop band ripple (normalized)**	**Transition width**
Karaboga[5]	Low pass	20	NR[a]	>0.08	>.0.09	>0.016
Najjarzadeh et al.[28]	Low pass Band pass	33 33	<29dB <25dB	NR[a] NR[a]	NR[a] NR[a]	NR[a] NR[a]
Luitel et al.[17]	Low pass	20	<27dB	0.291	0.270	>0.13

Mondal et al. [16]	Band pass Band pass Band pass	24 30 36	22.87 dB 24.07dB 24.49dB	NR[a] NR[a] NR[a]	NR[a] NR[a] NR[a]	NR[a] NR[a] NR[a]
Sarangi et al.[29]	Low pass Band pass	20 20	<27 dB <33 dB	>0.1 >0.2	>0.06 >0.05	>0.15 >0.07
Ababneh et al. [30]	Low pass	30	<30 dB(app.)	0.15	0.031	0.05
CSO[22]	Low Pass High Pass Band Pass Band Stop	20 20 20 20	33.99 33.62 33.47 33.11	0.164 0.132 0.163 0.144	0.01998 0.02085 0.01891 0.02479	0.0946 0.0941 0.1006 0.1034
Hime et al. [8]	Band pass	30	<33db	NRa	NRa	>0.1

3. CONCLUSION

The Preservation of shape of the input signal is the main advantage of the linear phase finite impulse response digital filters so they are widely used in the areas of discrete time signal processing applications. The designing methods of linear phase FIR filters are well established in all DSP books and filter design software packages. A brief review of linear phase FIR filter designing approaches has been discussed. The performance of techniques available in literature is compared in terms as; maximum stop band attenuation, maximum pass band ripple, maximum stop ripple and transition width.

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