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Designing Of IIR Filter With Multiobjective Genetic Algorithm

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Abstract— There are many methods available for filter designing. But problem arises when one has to find an optimal solution between two contradictory parameters, for example step response of filter should have minimum settling time and frequency response of filter should also have to satisfy constraints. There are many papers published on the GA based filter design, but those researches only include one parameter for optimization. In this paper we have shown the two objective fitness functions and found Paratoo Optimal Solution between those objectives. we have designed a low pass filter with the multi-objective GA technique and considered cutoff frequency and damping as objectives by which we have found the optimal coefficient of the IIR low-pass filter(b and a) and found desired step and frequency response.

Keywords- IIR filter, Optimization, Genetic Algorithm, Design, Communication

I. INTRODUCTION

There are many researches going on design of digital filters. For last few years evolutionary techniques are dominating traditional techniques for designing of any filter. Only filters are not dominated by these nature inspired algorithms while GA is used in many fields like robotics, control system, power system, Mathematical modeling etc. traditional formula based techniques are always accurate but limitations arrive when we have to take assumptions for formulation on any model or any problem, assumptions makes modeling less accurate and the solution found from traditional approaches are no more accurate. In this case nature inspired algorithms are most useful and provide better solution with assumptions. For an example in design of any filter the transient response are as important as the frequency response. But in most of the cases we compromise one of those parameters.

There are many paper published on GA based filter design and they show that they found better response than the traditional methods. Paper published till now use single objective fitness function for the optimization. In most of the publication they optimize the response by comparing designed response to the ideal response. Comparing response with the ideal response of filter may give satisfactory results but common problem with all evolutionary techniques is that they generate different population at every run so the final results may also differ [1]. Genetic algorithm will give better results when fitness function is accurately designed. For finding optimal results we have to design the fitness function with all assumptions. If there is any mistake in the fitness function then GA will not give optimal results.

In this paper I have formulate fitness function which takes care of frequency response and transient response of the filter. Main objective of this paper to illustrate the multi-objective GA problem for IIR filters and design the fitness function for the same. By which we found the desired response for the low pass filter.

II. METHODS

2.1. Infinite Impulse Response Filter Design

Digital filters are basically of two types FIR and IIR. FIR filters are known as Finite impulse response and IIR stands for Infinite impulse response. FIR filter does not depend on the output stage or we can say that there is no feedback from output to the input. The output of FIR filter is represented as given bellow:

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

Infinite impulse response filter's output also depends upon the previous output of filter so the output equation of the IIR filter is given as:

$$y(n) = \sum_{k=1}^{L} b_k x(n-k) - \sum_{k=0}^{M} a_k y(n-k) \qquad (2)$$

Where: y(n) and x(n)= Output and Input of the Filter

a_k and b_k = Coefficients of Filter

In designing of filter the desired parameter of the filter is translated in terms of the filter coefficients. FIR filters are designed with the windowing techniques and the IIR filter are derived from the analog filters by sampling of their transfer function model. All we need to find is the filter coefficient for designing purpose.

Genetic Algorithm required a fitness function to test fitness of population and according to which next generation is evolved. So formulating of fitness function is key assignment for applying the genetic algorithm. As we are using multi-objective GA, we considered cutoff frequency and damping for designing parameter. Consider the following second order transfer function for analog low pass filter.

$$H(s) = \frac{w_0^2}{s^2 + 2\xi w_0 s + w_0^2} \qquad (3)$$

Where: w_o= cutoff frequency

ξ = Damping

by taking the bilinear transform we can convert this analog filter in to the digital IIR filter by choosing proper sampling frequency ($f_{s)}$ or sampling time ($T=1/f_s$). We will finally have transfer function after conversion in the following form.

$$H(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}} \qquad (4)$$

For the fitness function we consider two variables, one variable is coefficient of'ʻs' and another variable is coefficient of 'ʻs^0'. Fitness function is for typically second order system if we want to design higher order system we can define variable 'b' and variable 'a' separately. That's make no difference, we can use either way. Less number of variable results faster convergence of population and reach optimum value in lesser time. So we should try to minimize the number of variables for which results better and faster meat of stopping criterion. The fitness function is given as following:

$$J_1(b_k, a_k) = -{}^{1}/_{(w_d - w_p)} \qquad (5)$$

$$J_2(b_k, a_k) = {}^{-1}/_{(\xi_d - \xi_p)} \qquad (6)$$

Where: w_d, ξ_d= Desired cutoff frequency and Damping

w_p, ξ_p= Calculated

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2.2. Genetic Algorithm and Filter Design

Genetic algorithm is the search based technique in which searching point is generated after each iterations. It is stochastic based searching. Process of Genetic algorithm is inspired from the genes as it is very clear by its name. We represent all the processes in the following flow chart.

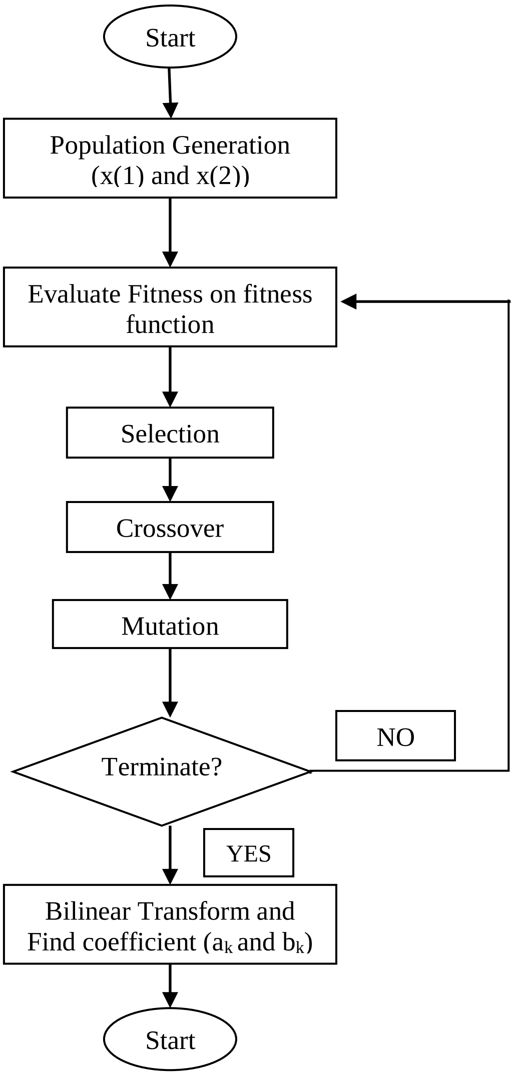

Figure 1: Filter Designing process Algorithm

Population tested on the fitness function and that should be minimum process is called evaluation of fitness. Than according to the GA in next iteration or generation present population generate new offspring. Selection is a process by which we select the new parents from current generation. By the crossing between those parents new offspring is generated and this process is called crossover. Mutation is final process by which current population's offspring replaced by some action. After the selection, crossover and mutation we have new population which will again follow the above procedure. Evaluating fitness selection crossover and mutation. And hence, at the end we check the stopping criteria which may be different for different application like number of iteration or minimum value range etc.

There are many techniques for all GA processes. MATLAB has pre-developed GA tool box which can be used by GUI or by code. And one can convert GUI setting to code just in a few simple steps. MATLAB toolbox provides wide range for GA settings. There are two functioning in MATLAB of GA one is 'ga' and second is 'gamulti'. The 'ga' is used for the single objective ga problem while 'gamulti' is used for the multi-objective GA fitness function. Multi-object GA provides Pareto optimal results (which we used) unlike the single objective ga which gives optimum value with respect to the objective function. Pareto solution draws a Pareto front which will draw between the objective one and objective two and gives expected numbers of solution which may be satisfied or partially satisfy both the objectives. Now selection of the solution depends upon the application and final choice is of the designer.

III. RESULTS

We tested our fitness function individually and combined both. And we found that we get optimum value when we used each objective separately. But problem is that both the objectives are contradicting each other. If we the need best step response then we have to compromise with frequency response and if we control cutoff frequency accuracy then we will find oscillations in step response. This forces us to design a multi-objective GA fitness function. We now tested the multi-objective GA function for finding Pareto optimal solution. We have numbers of optimal solutions after the GA Operations.

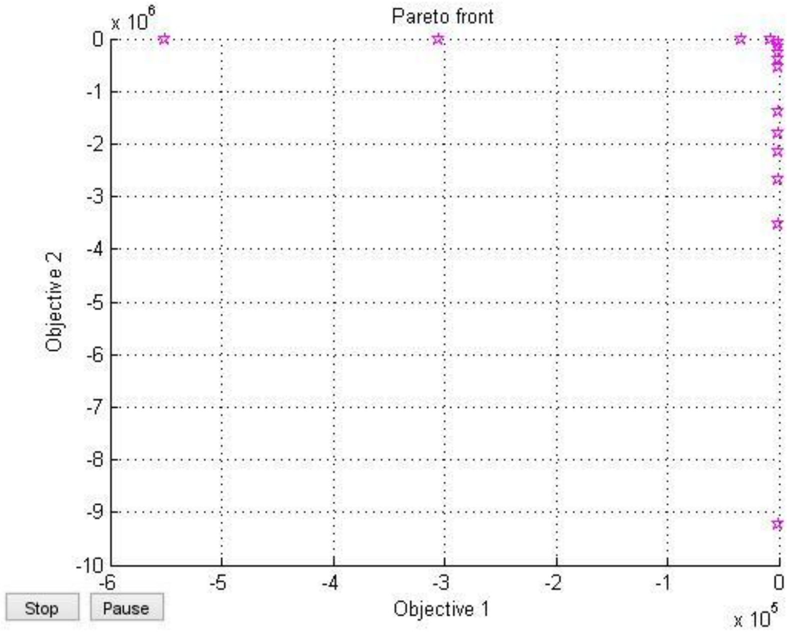

Figure 2: Pareto Front for second order Filter

Figure 2 shows the Pareto front which for second order IIR filter where objective one is represented by the equation 5 and objective 2 is represented by the equation 6. This graph is showing plotting the value of two objective functions which was derived from the filter's frequency response. We got final total seventeen value after this multi-objective GA operation. Table-1 shows the value of objective functions (FVAL) and respective coefficients ('a' and 'b').

It's very clear from the table 1 that the two objectives are contradictory. If we have to choose one from these solutions we definitely choose the solution number 8 this gives the best results in dilemma between those two objectives. If we see other solution then the j1 and J2 exist at two extremes. If we choose best J1 and we have to highly compromise with the J2 like in solution number 1 and vice-versa.

Table 1- GA optimized coefficients and performance index J_1 & J_2

S. No.	FVAL		Value of Coefficients					
	J_1	J_2	A			b		
1	-5.51E+05	-1.41E+00	1	-0.85107	0.951864	0.275198	0.550397	0.275198
2	-1.96E+01	-5.48E+05	1	-1.58485	0.657316	0.018116	0.036231	0.018116
3	-1.96E+01	-3.92E+05	1	-1.58485	0.657314	0.018116	0.036232	0.018116
4	-3.39E+04	-7.79E+01	1	-1.57571	0.653075	0.01934	0.03868	0.01934
5	-1.96E+01	-2.65E+05	1	-1.58485	0.657315	0.018116	0.036232	0.018116
6	-1.96E+01	-1.79E+06	1	-1.58486	0.657318	0.018115	0.036231	0.018115
7	-3.05E+05	-2.79E+01	1	-1.59707	0.67072	0.018412	0.036823	0.018412
8	-7.51E+03	-1.81E+02	1	-1.56872	0.647321	0.019649	0.039299	0.019649
9	-1.96E+01	-1.72E+05	1	-1.58485	0.657316	0.018116	0.036232	0.018116
10	-1.96E+01	-9.21E+06	1	-1.58487	0.657327	0.018114	0.036229	0.018114
11	-1.96E+01	-3.51E+06	1	-1.58487	0.657327	0.018114	0.036229	0.018114
12	-1.96E+01	-2.68E+06	1	-1.58486	0.657323	0.018115	0.03623	0.018115
13	-1.96E+01	-1.38E+06	1	-1.58486	0.657318	0.018115	0.036231	0.018115
14	-1.96E+01	-2.15E+06	1	-1.58486	0.657319	0.018115	0.03623	0.018115
15	-1.96E+01	-1.38E+06	1	-1.58486	0.657318	0.018115	0.036231	0.018115
16	-1.96E+01	-9.21E+06	1	-1.58487	0.657327	0.018114	0.036229	0.018114
17	-1.96E+01	-7.51E+04	1	-1.58486	0.657321	0.018116	0.036231	0.018116

Pole-Zero Map and Step Response is given in figure 2 and Frequency response is given in figure 3. All the poles found from the solutions are very close to each other because the deference between coefficients is very less and looks overlapped on graph. We set the cutoff frequency 1 Hz and sampling frequency of 4 Hz at the absolute gain 0.91 and damping is set to the 0.707. Designed filter response satisfied both condition. If we check frequency response then we will see that at 0.91 gains the frequency is 0.89 Hz and damping for this s response is 0.7. While other solution also provides 0.93 Hz and 0.68 damping. So here we can choose optimum results as according to the application.

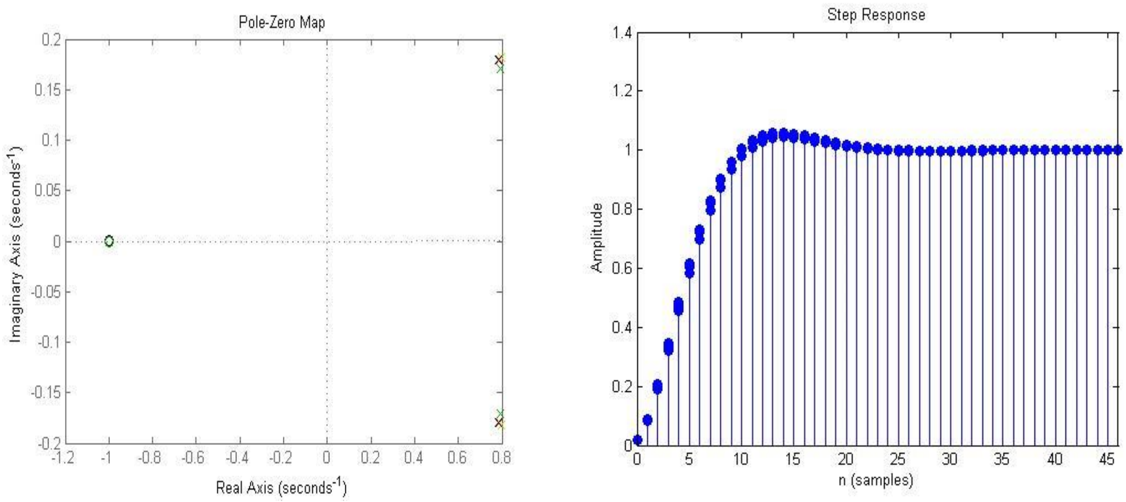

Figure 3: Pole zero Map and Step Response of all seventeen solutions separately and all solution in one graph (only for stable filter)

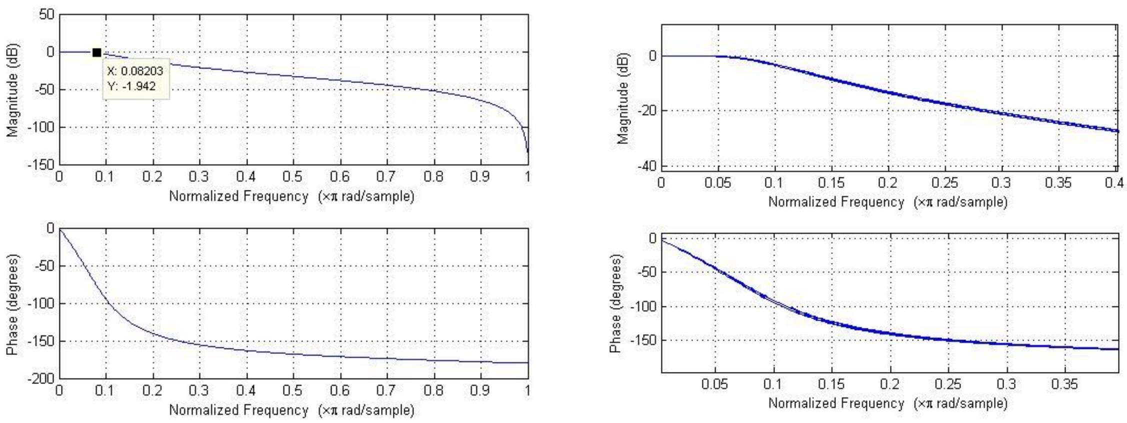

Figure 4: Frequency Response of Optimal design (i.e. Solution no. 8) and all solution's frequency response (only for stable system)

III. CONCLUSION

By using multiobjective GA fitness function, we determine the optimal solution between two objectives. In this paper, a low pass IIR digital filter has been designed with algorithm called GA which provides a PARETO optimal solution. The GA algorithm is used as a stochastic search method by performing numerous level of iteration which provides faster and better performance more thoroughly. Contradiction occurs in two optimal solutions but by taking any one as major either sampling frequency or damping we precedes the process. The above given example demonstrates the optimization and versatility of the proposed work. When we have to design filter with the minimum component or by minimum order we the have restriction of components when we are working with higher accuracy so this terms us to use genetic algorithm the analog filter components have role of rate due to which they cannot stand in many environmental condition and are not as accurate as digital filters higher order filter gives better frequency response but processing of those filters cab be slower and also there are lots of assumption for digital filter designing. Nature inspired algorithm are best suitable for these type of problem where there is no mathematical equation for the output.

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