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Design of Digital IIR filter by using Multiobjective Evolutionary Algorithm

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***Abstract*- Filters are used to discriminate an undesired frequency from a given signal which is having both desired and undesired signals. In this paper, we will design a recursive filter with a help of multiobjective evolutionary algorithm. We will verify that the effectiveness and efficiency of MOEA on low pass(LP), high pass(HP),Band pass(BP) and band stop(BS) Chebyshev filter.**

Keywords: IIR filter, multiobjective optimization, evolutionary algorithm.

I. INTRODUCTION

Filters are usually used to discriminate a frequency or a band of frequency from a given signal which is normally a mixture of both desired and undesired signals. The undesired portion of the signal commonly comes from noise sources such as power line hum etc.. or other signals which are not required for the current application. Filters are classified as analog and digital. An analog filter uses analog electronic circuits made up from components such as resistors, capacitors and op amps to produce the required filtering effect. Such filter circuits are widely used in such applications as noise reduction, video signal enhancement, graphic equalizers in hi-fi systems, and many other areas. Although analog filters are excellent in some aspects , especially in cost, they do have some serious demerits. One of the drawback of analog filters is there non-linear phase characteristics. This is not a serious problem in many of the applications, but it become serious in applications like telecommunication, voice processing etc... Another drawback is the less sharp cut-off frequency. It is possible to increase roll-off rate by cascading filter stages, but this would increase system cost and complexity. On the other hand, it is possible to achieve all these characteristics fairly by using a digital filter.

Digital filters are classified as infinite impulse response(IIR) or finite impulse response(FIR) depending upon whether the response of the filter is dependent on only the present input values or on the present inputs as well as previous outputs. The difference between IIR and FIR filter is given below:

IIR filters are difficult to control and have no particular phase, whereas FIR filters make a linear phase always possible. IIR can be unstable, whereas FIR is always stable. IIR, when compared to FIR, can have limited cycles, but FIR has no limited cycles. IIR is derived from analog, whereas FIR has no analog history. FIR filters are dependent upon linear-phase characteristics, whereas IIR filters are used for applications which are not linear. FIR's delay characteristics is much better, but they require more memory. The high computational efficiency of IIR filters, with short delays, often make the IIR popular.

An IIR filter is computed by the basic formula that combines inputs x[n] and outputs y[n] as follows:

$$y[n]=\sum_{k=0}^{M} b_k x[n-k]+\sum_{k=1}^{N} a_k y[n-k] \qquad (1)$$

The coefficients b_k are the "feed forward" coefficients, because they only act on the input signal x[n], and the coefficients a_k are the "feedback" coefficients, because they act on past outputs y[n]. We have already seen that by using the Z-transform that we obtain a simple input-output relationship:

$$Y(z)=H(z)\,X(z) \qquad (2)$$

The transfer function of the IIR filter is:

$$H(z)=\frac{b_0+b_1 z^{-1}+\cdots+b_m z^{-M}}{1-a_1 z^{-1}-\cdots-a_N z^{-N}} \qquad (3)$$

Notice the numerator and denominator are both polynomials, and therefore, like all polynomials, have roots. The roots of the numerator are called the "zeros" of the filter and the roots of the denominator, are called the "poles"[1].

II. OPTIMAL PROBLEM FORMULATION

Like most other engineering problem, the design of IIR filters involves multiple, often conflicting, design criteria and specifications, and finding an optimum design is, therefore not a simple task. Direct search methods and gradient based methods usually lead to sub-optimal designs. Consequently, there is a need for optimization-based methods that can be used to design IIR filters that would satisfy prescribed specifications. However, optimization problems for the design of digital IIR filters are often complex, highly nonlinear, and multimodal in nature. The optimization method should lead to global optimum of the objective function with a minimum amount of computation. Optimization algorithm requires comparison of a number of a design solution, it is usually time consuming and computationally expensive, thus, the optimization procedure must only be used in those problems where there is a definite need of achieving a quality product or a competitive product. Therefore, they tend to locate minima in the locale of the initialization point. Steps involved in an optimal design formulation process are:

a) *Choose design variables*
b) *Formulate constraints*
c) *Formulate objective function*
d) *Set up variable bounds*
e) *Choose an optimization algorithm*
f) *Obtain solutions*

Classical optimization methods are generally fast and efficient, and have been found to work reasonably well for the design of IIR filters. These methods are very good in locating local minima but unfortunately, they are not designed to discard inferior local solutions in favor of better ones. In recent years, variety of algorithms has been proposed for global optimization including multivariable optimization algorithms and nontraditional optimization algorithms [2].

III. MULTIOBJECTIVE EVOLUTIONARY ALGORITHIM

Traditionally, most EA based digital IIR filter design works treat digital IIR design as a single objective problem with some supplementary conditions, while the multiple criteria design has not attracted sufficient attention. The single objective methods inevitably cause the loss of consideration of the secondary or tertiary objectives, which are usually related to the linear phase response error and order of IIR filter. These factors are also very important in digital IIR filter design. The linear phase response error is not considered, which may result in large distortion indicates that IIR filters designed in such single objective optimization way can only be implemented in the applications, where phase responses are not very important. Besides, for single objective optimization algorithms, the users have to set weights to combine several criterions into one single optimization objective. Especially, the setting of weights always requires strong background of both designing digital IIR filter and optimization algorithm. Furthermore, a lot of previous works do not take the optimization of the filter structure into account, which means that the order of IIR filter must be determined beforehand. It is well understood that higher order of IIR filter, more complex the structure is and more expensive the cost is. In this case, EAs have not shown their full flexibility and potentiality in the tasks of designing optimal IIR filters

So in this paper we will consider both magnitude and phase response error together [3].

A. Evolutionary Approach

a) *Initialize the population*
b) *Crossover*
c) *Mutation*
d) *Selection*
e) *Update the population if result is not satisfied*

Overview of the algorithm which we use to obtain our desired optimal results

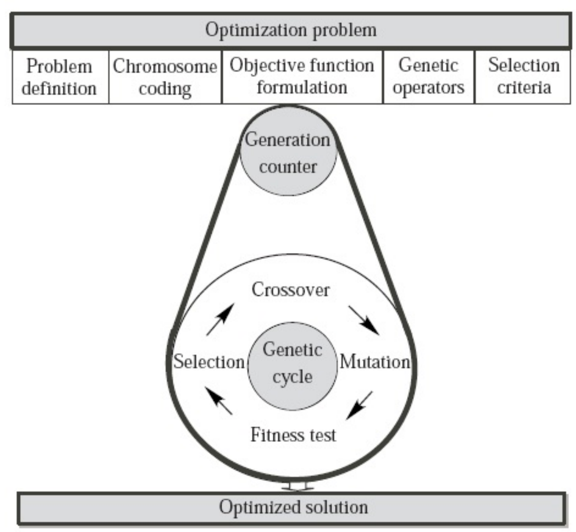

Figure 1 :pictorial overview of the algorithm [5]

IV. APPLICATION

In order to evaluate the chromosomes representing possible IIR filters in the population basic error functions are usually used. The chromosomes which have higher fitness values represent the better filters. In the filter design the following error functions can be used : Mean Squared Error (MSE), Least Mean Squared Error (LMS), Mini max Error or Mean Absolute Error (MAE). The expressions of these functions are given below:

a) Mean Squared Error (MSE)

$$MSE= \sum_f[|H_1(f)| - |H(f)|]^2 \quad (4)$$

b) Least - Mean Squared Error (LMS)

$$LMS= \{\sum_f[|H_1(f)| - |H(f)|]^2\}^{1/2} \quad (5)$$

c) Mean Absolute Error (MAE)

$$MAE= \sum_f[|H_1(f)| - |H(f)|] \quad (6)$$

$H_1(f)$ = Magnitude response of the ideal filter

$H(f)$ = Magnitude response of the designed filter

When the error functions were directly used as they are in Equations, the instability problem and non-minimum phase problem appeared. In order to overcome this problem the basic error functions given above were modified. It is assumed that the number of poles that causes the instability is q_p and the number of zeros that causes the non-minimum phase is q_z and the error function used is when the error functions were directly used as they are in Equation, It is assumed that the number of poles that causes the unstability is q_p and the number of zeros that causes the non-minimum phase is q_z and the error function used is e(f).

Then the objective function which is able to provide optimal magnitude response, stability and minimum-phase can be defined as,

$$\varphi(f)= e(f) + q_p w_p + q_z w_z \quad (7)$$

w_p, w_z are weight parameter

w_p, w_z have to be chosen appropriately. As the number of poles that cause the unstability increases, the effect of these poles on the error function will increase proportionally. Hence, by means of objective function the poles which are located out of the unit circle are pulled into to the inside of the unit circle.

Similarly, as the number of zeros that cause the non minimum phase increases, the effect of these zeros on the error function will increase proportionally. Hence, by means of objective function these zeros which are located out of the unit circle are pulled into to the inside of the unit circle. When all the poles and zeros are pulled inside the unit circle, the error function will be equal to the objective function since q_p = 0 and q_z = 0.

The fitness function used in this work is given by

$$Fitness= \frac{1}{\varphi(f)} \quad (8)$$

When the value of w_z is chosen too high, the value of the pole term becomes dominant on objective function and therefore, the algorithm might have difficulties with converging and finally could not reach the optimum solution. When the value of w_p is chosen too low, the influence of the pole term on the objective function becomes too small and hence this ignores the pole term and the designed filter might become unstable.

so weight parameter should be chosen carefully so the desired magnitude response can be obtained

Only one of the error functions is usually used as the error function. However, as mentioned above to optimize the magnitude response and to provide the stability and minimum phase we need
to use all of these error functions, simultaneously. In order to realize this, LMS error function is employed in the pass band region, MAE error function is employed in the transition band region and MSE error function is employed in the stopband region simultaneously during the design process. This is shown in figure 2

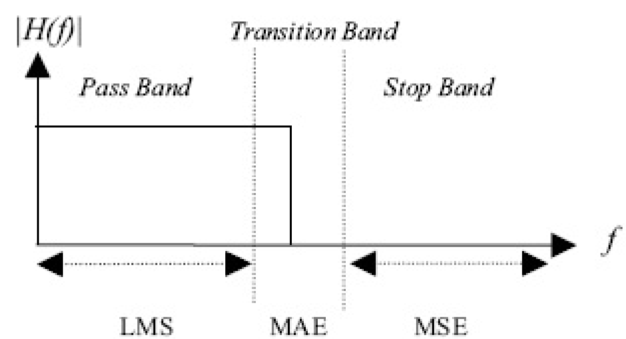

Figure 2: showing the use of error function for respective band

[4]

V. CONCLUSION

With the use of MOEA in this paper, an low pass(LP), high pass(HP),Band pass(BP) and band stop(BS) Chebyshev filter with better efficiency and reduce computational cost and also obtain the IIR filter with higher linear characteristics and stability than others conventional algorithm to implement an IIR filter .

VI. FUTURE WORK

In future I will implement a Chebyshev IIR filter with algorithm described in this paper and also calculate the group delay in the filter in future.

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VIII. REFERENCES

[1] John G. Proakis (2010) Digital signal processing, Prantice-Hall International, inc., New Jersey

[2] Kalyanmoy Deb (2010) Optimization for engineering design, PHI learning Pvt. Ltd., New Delhi

[3] Yu Wang, Bin Li, Zhengdong Li, "Fixed-point digital IIR filter design using multi-objective optimization evolutionary algorithm" IEEE Transactions on Information Computing and Telecommunications (YC-ICT) youth conference , References Cited: 11 , 2010

[4] Nurhan Karaboga and Bahadir Cetinkaya," Design of Minimum Phase Digital IIR Filters by Using Genetic algorithm", Proceedings of the 6th Nordic Signal Processing Symposium - NORSIG 2004

[5] Sabbir U. Ahmad," Design of Digital Filters Using Genetic Algorithms", 2008

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