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# IIR digital filter design through genetic algorithm

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**ABSTRACT**

The Paper presents a simple computer-aided design approach for designing infinite-impulse response (IIR) digital filters. IIR filter is essentially a digital filter with Recursive responses. Since the error surface of digital IIR filters is generally nonlinear and multimodal, global optimization techniques are required in order to avoid local minima. There are many ways for the design of IIR Digital filters. This Paper Presents heuristic way for the designing IIR filters. In this Paper, Genetic Algorithm (GA) base evolutionary is proposed for design of IIR digital filter. GA is a well-known powerful global optimization algorithm, introduced in combinatorial optimization problems. The Simulation results for the employed examples are presented in this paper and can be efficiently used for IIR filter design.



## Introduction

Over the past several decades the field of Digital Signal Processing (DSP) has grown to important both theoretically and technologically. In DSP, there are two important types of Systems. The first type of systems performs signal filtering in time domain and hence it is known as Digital Filters. The second type of systems provide signal representation frequency domain and are known as Spectrum Analyzer. Digital filtering is one of the most powerful tools of DSP. Digital filters are capable of performance specifications that would, at best, be extremely difficult, if not impossible, to achieve with an analog implementation. In addition, the characteristics of a digital filter can be easily changed under software control. Digital filters are classified either as Finite duration unit pulse response (FIR) filters or Infinite duration unit pulse response (IIR) filters, depending on the form of unit pulse response of the system. In the FIR system, the impulse response sequence is of finite duration, i.e., it has a finite number of non zero terms. Digital infinite-impulse-response (IIR) filters can often provide a much better performance and less computational cost than their equivalent finite-impulse-response (FIR) filters [3] and have become the target of growing interest [1], [2], [4]. However, because the error surface of IIR filters is usually nonlinear and multimodal, conventional gradient-based design methods may easily get stuck in the local minima of error surface [4], [5].Therefore, some researchers have attempted to develop design methods based on modern heuristic optimization algorithms such as genetic algorithm (GA) [6]–[9], simulated annealing (SA) [10], tabu search (TS) [5] etc.

This Paper is organized as follows: In Section II, IIR digital filter design aspects are discussed. In section III, Genetic Algorithm (GA) approach is briefly mentioned. The Genetic Algorithm (GA) related to filter design is proposed in Section IV. The simulation results of designed examples used is briefly described in Section V. The Conclusion and future scope is described in Section VI.

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## IIR filter design issues

Digital filters are classified as Recursive and Non-Recursive filters. IIR Digital Filters are designed by using the values of both the past outputs and the present input, an operation brought about by convolution. If such filters subjected to an impulse then its output need not necessarily become zero. The infinite impulse response of such a filter implies the ability of the filter to have an infinite impulse response. This indicates that the system is prone to feedback and instability. Consider the IIR filter with the input-output relationship governed by:

$$y(k)+\sum_{i=1}^{M} b_i y(k-i)=\sum_{i=0}^{L} a_i x(k-i)$$

where $x(k)$ and $y(k)$ are the filter's input and output, respectively, and $M$ $(\geq L)$ is the filter order. The transfer function of this IIR filter can be written in the following general form:

$$H(z)=\frac{A(z)}{B(z)}=\frac{\sum_{i=0}^{L} a_i z^{-i}}{1+\sum_{i=1}^{M} b_i z^{-i}}$$

An important task for the designer is to find values of $a_i$ and $b_i$ such that the magnitude response of the filter approximates a desired characteristic while preserving the stability of the designed filter. The stability is assured if all the poles of the filter lie inside the unit circle in the z-plane. The Digital filters have various stages for their design. The flow chart of the Design of Digital filter is shown in fig. 1.

## Genetic Algorithm

Genetic Algorithms (GA) are stochastic search methods that can be used to search for an optimal solution to the evolution function of an optimization problem. Holland proposed genetic algorithms in the early seventies as computer programs that mimic the natural evolutionary process.

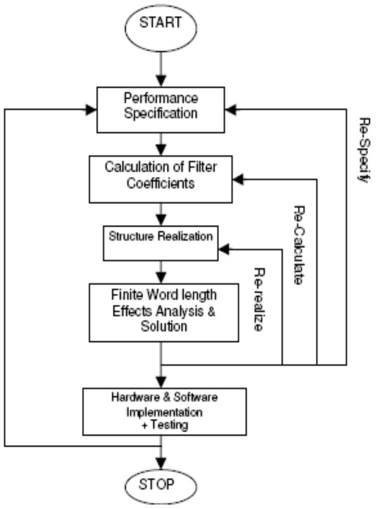



**Fig. 1. Flow chart of Digital filter design.**

De Jong extended the GAs to functional optimization and a detailed mathematical model of a GA was presented by Goldberg in 1975. GAs manipulates a population of individuals in each generation (iteration) where each individual, termed as the chromosome, represents one candidate solution to the problem. Within the population, fit individuals survive to reproduce and their genetic materials are recombined to produce new individuals as offsprings. The genetic material is modeled by some data structure, most often a finite-length of attributes. As in nature, selection provides the necessary driving mechanism for better solutions to survive. Each solution is associated with a fitness value that reflects how good it is, compared with other solutions in the population. The recombination process is simulated through a crossover mechanism that exchanges portions of data strings between the chromosomes. New genetic material is also introduced through mutation that causes random alterations of the strings. The frequency of occurrence of these genetic operations is controlled by certain pre-set probabilities. The selection, crossover, and mutation processes as illustrated in fig. 2 constitute the basic GA cycle or generation, which is repeated until some pre-determined criteria are satisfied. Through this process, successively better and better individuals of the species are generated.

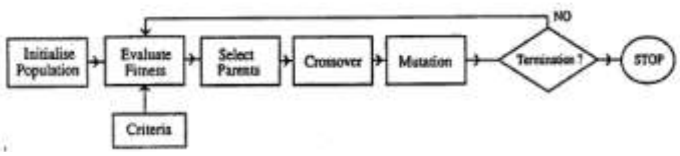



**Fig. 2 Basic Genetic Algorithm cycle.**

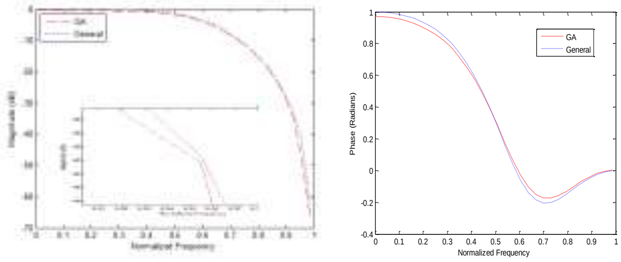
**GAS and filter design**

The error surface of digital infinite-impulse response (IIR) filters is generally nonlinear and multimodal, global optimization techniques are required in order to avoid local minima. In designing IIR digital filter, the values of ai and bi must be such that the magnitude response of the filter approximates a desired characteristic while preserving the stability of the designed filter. Although Simulated Annealing (SA) is easy to be implemented and good at local convergence, depending on the initial solution, it might often require too many cost function evaluations to converge to the global minima. Relatively little work has been published so far on GAs applied to analogues filters. A number of practical issues are important in analogues filter design. One is the choice of component values. A conventional form of GA is used to perform the design of IIR digital filter. The selected random number in range [0.17 0.76] has been found satisfactory. Fitness is evaluated in the normalized frequency range [0, 1] over a uniform grid of frequency point. Selection is the process of choosing structures for the next generation from the structures in the current generation. In the design of filter the Selection function used is the "Stochastic Universal Sampling", which allocate to each individual a portion of the wheel proportional to the individual's fitness. Crossover is the process of generating a child from two parents by taking a part from one of the parents and replaces it with the corresponding part from the second parent and vice versa. IIR Filter designing is performed by double point crossover between pairs of individuals and returns the current generation after mating. Mutation is a change done on some of the children resulted from the crossover process by flipping the value of one of the bits randomly. The benefit of such operation is to restore the lost genetic values when the population converges too fast.

The filter coefficients were encoded in terms of 16 bit binary string with initial Crossover and Mutation probability of 0.8 and 0.02 respectively, and the population size of 50 was assumed. The GA produced one solution that satisfied both magnitude and phase templates.

**Simulation results**

Simulation studies are carried for well known IIR filters (see Appendix I), which has been used by many authors as a "benchmark filter" for comparison purpose. The magnitude and phase response of first example is shown in fig. 3 in which a zoomed in curve for transition band is included.




(a) (b)

**Fig 3. Response of Low pass filter : (a) Magnitude response; (b) Phase response.**

The resulting coefficients of the low pass filter are shown in Table1. A comparison of coefficients is done with the MATLAB filter design tool.

**Table 1Coefficients of Low pass filter designed**

| Name of Method | Order of filter | Coeff. of Numerator | Coeff. Of denominator |
|---|---|---|---|
| *fda* tool | 3 | 1.0, 2.0, 1.0 | 1.0, 0.0214, 0.17165 |
| Proposed method | 3 | 0.3667, 0.7213, 0.3525 | 1.0, 0.3116, 0.1790 |

The fig. 4 illustrates the magnitude and phase response of second example in which a zoomed in curve for transition band is included.

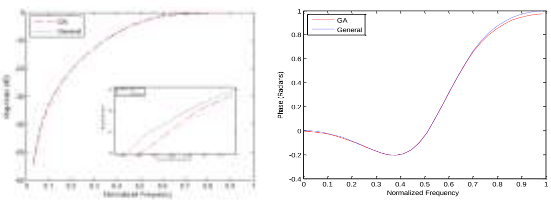



**Fig. 4. Response of High pass filter : (a) Magnitude response; (b) Phase response.**

Similarly, Table 2 gives the coefficients of High pass filter under same specifications. The designed example is compared with the traditional method.

**Table 2**
**Coefficients of High pass filter designed**

| Name of Method | Order Of filter | Coeff. of Numerator | Coeff. of denominator |
|---|---|---|---|
| *fda* tool | 3 | 1.0, -2.0, 1.0 | 1.0, -1.99, 0.9985 |
| Proposed method | 3 | 0.2699, -0.5500, 0.2711 | 1.0, 0.0537, 0.1662 |

## Conclusion

Genetic Algorithm is a global optimization technique. In this paper, GA-based design of IIR digital filters has been proposed, and the benefits of GA for designing digital filter have been studied. The simulation results show that GA has better, or at least equivalent, global search ability and convergence speed than others. Thus it is believed that the proposed algorithm is capable of quick and high performance.

## Appendix I

*Example 1:* In the first example, design a low pass filter with following specifications: Pass/Stop band ripples 1dB/ 15dB, and band edges 200Hz / 400Hz and a sampling frequency of 1000Hz.

*Example 2:* This example is taken for design of a high pass filter with following specifications: Pass/Stop band ripples 1dB/ 75dB, and band edges 600Hz / 200Hz and a sampling frequency of 1500Hz.

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