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Optimal Design of Digital Integrator Using Genetic Algorithms

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Abstract: - In this paper, we design the digital integrator using the stochastic search techniques inspired by the principles of natural selection and natural genetics. Analytical design methods suffer from slow convergence to the optimal solution to a problem; heuristics based genetic algorithm can be a more efficient alternative to optimize the problem. In case of analytical design methods the filter coefficient are locally optimized. The stochastic search techniques will give robust and globally optimized solution. We are applying genetic algorithms (GA) which is a adaptive method used to solve and optimized the filter design problem. GA is based on the genetic processes of biological organisms. GA used the principle of natural selection and 'survival of the fittest'. In this paper, we consider absolute magnitude error as the design parameter that decides the efficiency of the design filter. Fitness function used is explained. The simulation results shows the proposed integrator outperform the existing integrator in term of absolute magnitude error and also in terms of relative magnitude error. Result also shows that proposed integrator is comparable to that of the ideal integrator. The Results reveals that the magnitude response of the design integrator closely approaches the ideal integrator response. Numerical results shows that the design error is reduce to a value equal to that of 0.3% which is comparatively smaller than the other designed integrators. The absolute magnitude error obtained is 0.3%.

Index Terms: - **Absolute magnitude error, Relative magnitude error, Digital integrator, Genetic algorithm (GA), Digital filter.**

I. INTRODUCTION

Digital integrators are of considerable interest as they are widely used in the areas of control, biomedical engineering and radar. For such system with possible noise and uncertainties and design constraints, the solution to the optimization [1-3] problem is by no means trivial. The following issues need attention: 1) the optimization technique selected must be appropriate and must suit the nature of the problem; 2) all the various aspects of the problem have to be taken into account; 3) all the system constraints should be correctly addressed; and 4) a comprehensive yet not too complicated objective function should be defined. The frequency response of an ideal digital integrator is

$$H_{int}(\omega) = {}^{1}/_{j\omega} \qquad (1)$$

Where $j = \sqrt{-1}$ and ω is the angular frequency in radians. Many digital integrators have been proposed by using Newton–Cotes integration rule. These includes Al-Alaoui's first-, second- and third-order integrators and differentiators [4–9] [16][17], Ngo's third-order integrator and differentiator [10], Pei-Hsu's second-order differentiator [11]. Different approaches for the design of digital integrators are as follows simple linear interpolation between the magnitude responses of the classical rectangular, trapezoidal and Simpson digital integrators [12], linear programming optimisation approach [13], optimising the pole-zero locations [14]-[15], Simulated Annealing, Genetic Algorithms [1], and Fletcher and Powell Optimization. Various methods exist that address the optimization problem under different conditions.

Digital filters can be classified into two major classes, finite impulse response (FIR) filters and infinite impulse response (IIR) filters. The design methods of digital integrator generally can be classified into two categories. One is the linear phase finite-impulse response (FIR) filter approach in which the filter coefficients are determined by using maximal flatness constraints the other is the infinite-impulse response (IIR) filter method in which the filter coefficients are obtained directly from well known rectangular, trapezoidal and Simpson methods of numerical integration.

This paper presents the design the digital integrator using the stochastic search techniques inspired by the principles of natural selection and natural genetics. In case of analytical design methods the filter coefficient are locally optimized. The stochastic search techniques will give robust and globally optimized solution. We are applying genetic algorithms (GA) which is a adaptive method used to solve and optimized the filter design problem. GA is based on the genetic processes of biological organisms. GA used the principle of natural selection and 'survival of the fittest'.

The rest of the paper is organized as follows: In section II, explain the genetic algorithm that is based on the behaviour of genes. In Section III, flow chart of genetic algorithm along with important optimization parameter is presented. Section IV explains the designing of optimal digital integrator of different order based on this nature inspired algorithm. In Section V, shows the simulation results of the integrator for the evaluation of the performance in terms of absolute magnitude error. Finally, a conclusion is made.

II. GENETIC ALGORITHM

Genetic algorithms (GAs) [2] are the main paradigm of evolutionary computing. GAs is inspired by Darwin's theory about evolution – the “survival of the fittest". In nature, competition among individuals for scanty resources results in the fittest individuals dominating over the weaker ones.

1. GAs are the ways of solving problems by mimicking processes nature uses; ie., Selection, Crosses over, Mutation and Accepting, to evolve a solution to a problem.
2. GAs is adaptive heuristic search based on the evolutionary ideas of natural selection and genetics.
3. GAs is intelligent exploitation of random search used in optimization problems.
4. GAs, although randomized, exploit historical information to direct the search into the region of better performance within the search space.
5. The biological background (basic genetics), the scheme of evolutionary processes, the working principles and the steps involved in GAs are illustrated in next few slides.

GAs encodes the decision variables of a search problem into finite-length strings of alphabets of certain cardinality. The strings which are candidate solutions to the search problem are referred to as chromosomes, the alphabets are referred to as genes and the values of genes are called alleles.

To evolve good solutions and to implement natural selection, we need a measure for distinguishing good solutions from bad solutions. The measure could be an objective function that is a mathematical model or a computer simulation, or it can be a subjective function where humans choose better solutions over worse ones. In essence, the fitness measure must determine a candidate solution’s relative fitness, which will subsequently be used by the GA to guide the evolution of good solutions.

III. STEPS TO FIND OPTIMAL SOLUTION USING GENETIC ALGORITHM

In this section, Steps to find optimal solution using Genetic Algorithm are presented and also the flow chart representation is also shown in fig. 1. Following are step to design optimal digital integrator.

1. [Start] Generate random population of n chromosomes (i.e. suitable solutions for the problem).
2. [Fitness] Evaluate the fitness f(x) of each chromosome x in the population.
3. [New population] Create a new population by repeating following steps until the new population is complete.
   a. [Selection] Select two parent chromosomes from a population according to their fitness (better the fitness, bigger the chance to be selected)
   b. [Crossover] With a crossover probability, cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.
   c. [Mutation] With a mutation probability, mutate new offspring at each locus (position in chromosome).

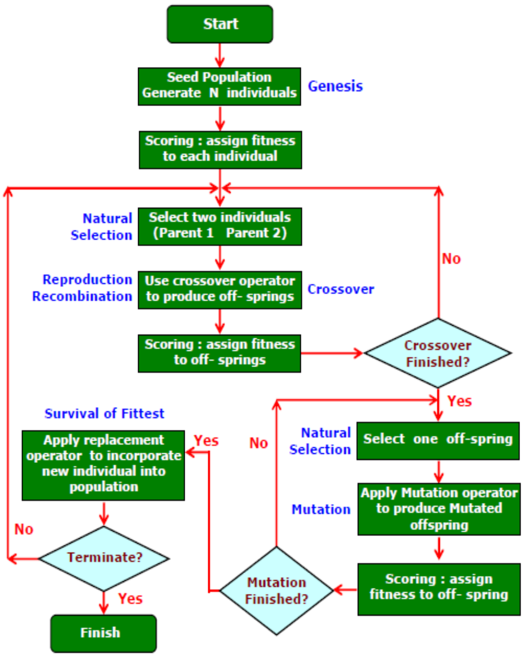

Fig: 1 Flow chart of Genetic Algorithm

4. [Accepting] Place new offspring in the new population
5. [Replace] Use new generated population for a further run of the algorithm
6. [Test] If the end condition is satisfied, stop, and return the best solution in current population
7. [Loop] Go to step 2

IV. OPTIMAL DIGITAL INTEGRATOR

Proposed second order filter is obtained as

$$H_{int\_GA\_2} = \frac{1 + 0.7945z^{-1} + 0.0832z^{-2}}{1.1543 - 0.4464z^{-1} - 0.7079z^{-2}}$$

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For the third order filter, the zeros and poles of the second order filter are used as starting points. Thus, the filter becomes

$$H_{int\_GA\_3} = \frac{1 + 0.7981z^{-1} + 0.0884z^{-2} + 0z^{-3}}{1.1543 - 0.4432z^{-1} - 0.7060z^{-2} - 0.0041z^{-3}}$$

The fourth order filter was built upon using the third order

$$H_{int\_GA\_4} = \frac{1 + 0.9054z^{-1} + 0.1713z^{-2} + 0.0066z^{-3} + 0z^{-4}}{1.1543 - 0.3170z^{-1} - 0.7560z^{-2} - 0.0817z^{-3} - 0.000}$$

V. SIMULATION RESULTS

The optimal designs of digital integrator are performed using optimization technique known as genetic algorithm. Simulation has been done in MATLAB and optimization toolbox of matlab. We are optimizing the filter coefficient of IIR integrator using genetic algorithm. Initially, population is to be selected. Then design the objective function to design the integrator such that the response of the filter approximates the ideal response of the integrator. For that purpose different techniques are employed here we are using optimization of filter coefficient using nature inspired algorithm namely genetic algorithm. Optimization using genetic algorithm must follows the following step such that filter to be design will approximate the response of the ideal response. Following control parameters are too considered while optimizing the filter coefficients as shown in table 1.

Table 1 Control Parameter

Parameter	Genetic Algorithm
Population size	100
Iteration cycles	400
Crossover rate	1.5
Crossover	Single Point Crossover
Mutation rate	0.05
Mutation	Gaussian Mutation
Selection	Roulette

Fig.2 shows the absolute magnitude error for optimized Al-Alaoui first order integrator. Fig.3 shows the comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order and genetic algorithm optimized second order integrator. Fig.4 shows the comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order, genetic algorithm optimized second order and genetic algorithm optimized third order integrator. Fig.5 shows the comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order, genetic algorithm optimized second order, genetic algorithm optimized third order and genetic algorithm optimized fourth order integrator. Fig.6 shows the comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order, genetic algorithm optimized second order, genetic algorithm optimized third order, genetic algorithm optimized fourth order integrator and existing integrator.

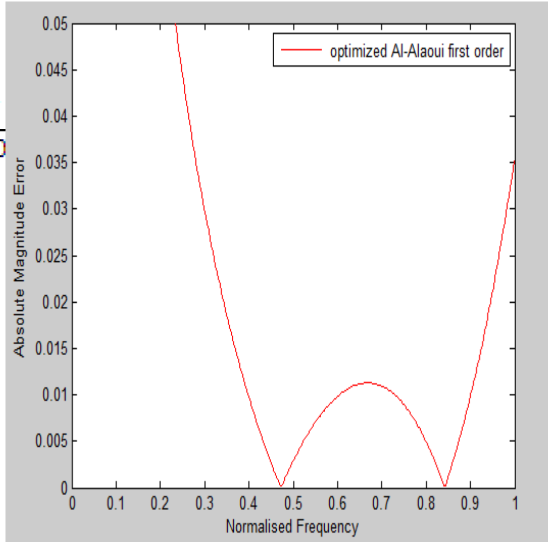

Fig.2 Absolute magnitude error for optimized Al-Alaoui first order integrator

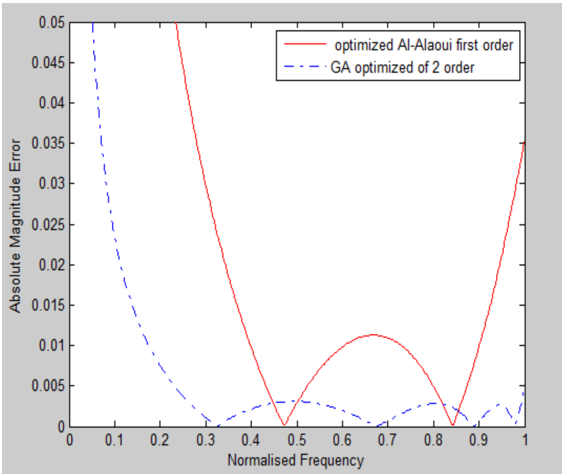

Fig.3 comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order and genetic algorithm optimized second order integrator

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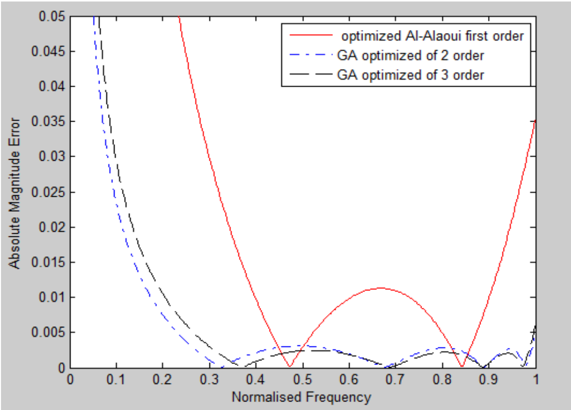

Fig.4 comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order, genetic algorithm optimized second order and genetic algorithm optimized third order integrator

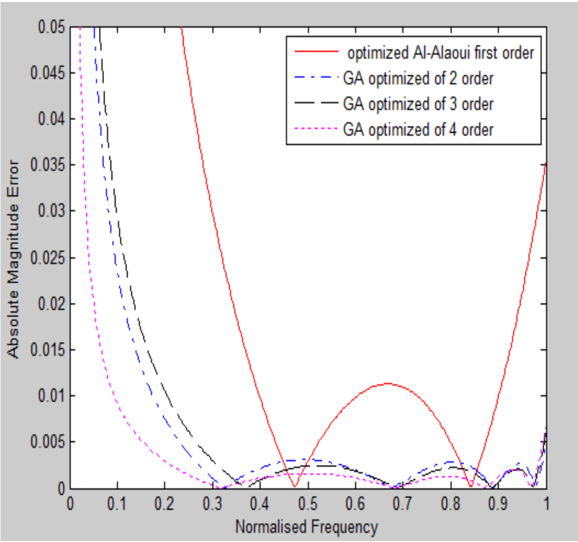

Fig.5 comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order, genetic algorithm optimized second order, genetic algorithm optimized third order and genetic algorithm optimized fourth order integrator

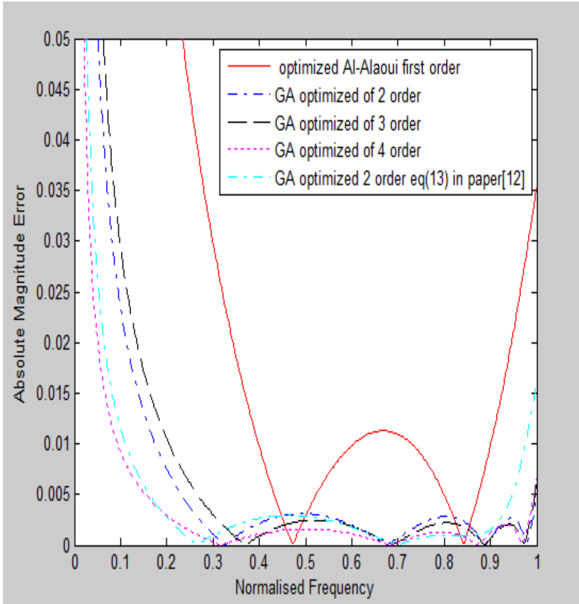

Fig.6 comparative analysis of Absolute magnitude error for optimized Al-Alaoui first order, genetic algorithm optimized second order, genetic algorithm optimized third order, genetic algorithm optimized fourth order integrator and existing integrator

VI. CONCLUSIONS

In this paper, we present the design of digital integrator using the stochastic search techniques inspired by the principles of natural selection and natural genetics. We are applying genetic algorithms (GA) which is a adaptive method used to solve and optimized the filter design problem. GA is based on the genetic processes of biological organisms. GA used the principle of natural selection and 'survival of the fittest'. Here, we consider absolute magnitude error as the design parameter that decides the efficiency of the design filter. Fitness function used is explained. Result also shows that proposed integrator is comparable to that of the ideal integrator. The Results reveals that the magnitude response of the design integrator closely approaches the ideal integrator response. Numerical results shows that the design error is reduce to a value equal to that of 0.3% which is comparatively smaller than the other designed integrators. The absolute magnitude error obtained is 0.3%.

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