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Design of 15th Order Length 32 Digital Differentiator Using Genetic Algorithm

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Abstract- An essential tool for signal processing is the digital differentiator. It is used in a wide range of devices, including high frequency radars and low frequency biomedical equipment. Digital differentiators are an essential building piece of emerging areas like online signature verification and touch screen tablets. Although a variety of techniques have been established to build differentiators of all kinds, parameter optimization still has room for improvement. The challenge of designing differentiators is difficult. This work presents the design of a fifteenth order digital differentiator using the Genetic Algorithm, one of the optimization approaches.

Index Terms- DDs,FIR,GA,TF.

I. INTRODUCTION

Basic FIR filter is characterized by

$$y(n) = \sum_{k=0}^{N-1} h(k)x(n-k)$$

and the transfer function of the system is given by

$$H(z) = \sum_{k=0}^{N-1} h(k)z^{-k}$$

Where h(k) is the impulse response coefficients of filter, N is the filter length (number of coefficients). FIR filters can have exactly linear phase response.

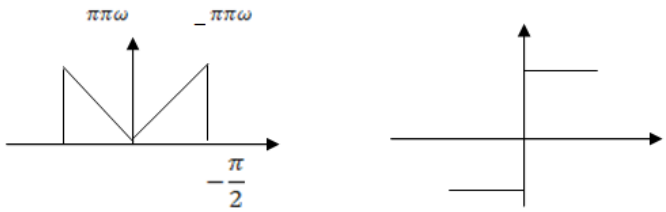

Fig.No.1

- **Filter Specification:** Include stating the type of the filter as LPF, desired amplitude/ phase response and tolerance, sampling frequency etc.
- **Coefficient Calculation:** Determine the coefficients of a transfer function H(z), which satisfy the filter specifications.
- **Realization:** converting transfer function H(z) into a suitable filter network or structure.
- **Analysis of Finite Word Length Effects:** analyze the effect of quantizing the filter coefficients and the input data as well as the effect of carrying out the filtering operation using fixed word length on the filter performance.
- **Implementation:** Producing software code and hardware and performing actual filtering.

An ideal differentiator has the frequency response as defined below:

$$H_d(\omega) = j\omega \; -\pi \le \omega \le \pi$$

Hence, the magnitude and phase responses are

$$|H_d(\omega)| = |\omega| \; -\pi \le \omega \le \pi$$

And

$$\theta(\omega) = \angle H_d(\omega) = \begin{cases} \frac{\pi}{2}, & \omega > 0 \\ 0 & \omega = 0 \\ -\frac{\pi}{2}, & \omega < 0 \end{cases}$$

The corresponding sketch of magnitude and phase responses of an ideal differentiator is

The unit sample response of $h_d(n)$ is obtained by taking inverse DTFT of $H_d(\omega)$ as:

$$h_d(n) = \frac{1}{2\pi}\int_{-\pi}^{\pi} H_d(\omega)e^{j\omega n}\, d\omega$$

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We can design digital differentiator of any order. Higher order digital differentiators have received considerable importance in some applications such as calculation of geometric moments and biological signal processing.

A perusal of literature suggests that different types of design techniques and algorithms are being proposed from time to time and are used for the design frequency selective FIR, log FIR, complex coefficient half band, and notch filters, and first and higher order digital differentiator, Integrators and Hilbert transformers etc.

II. LITERATURE SURVEY

A paper titled "Linear Phase Second Order Recursive Digital Integrators and Differentiators" by Madhu JAIN 1, Maneesha GUPTA 2, Nitin JAIN, proposed that the design of linear phase second order recursive digital integrators and differentiators is discussed. New second order digital integrators have been designed by using Genetic Algorithm (GA) optimization method. Thereafter, by modifying the transfer function of these integrators appropriately, new digital differentiators have been obtained. The proposed digital integrators and differentiators accurately approximate the ideal ones and have linear phase response over almost entire Nyquist frequency range. The proposed operators also outperform the existing operators in terms of both magnitude and The proposed integrators and differentiators accurately approximate the ideal ones with very small absolute relative error and linear phase response over almost entire Nyquist frequency range. It is verified by the simulation results that the proposed second order wideband operators outperform all the existing operators in frequency domain analysis. The low order (second order), less relative error and linear phase response of the proposed integrators and differentiators make them useful in real time applications phase response.

A paper titled "Design of Digital Differentiator to Optimize Relative Error" by Vinita V. Sondur,Vilas B. Sondur, and Narasimha H. Ayachit., It was observed that the Weighted least-square (WLS) technique, including the modifications, results in equiripple error curve. The resultant error as a percent of the ideal value is highly non-uniformly distributed over the range of frequencies for which the differentiator is designed. The present paper proposes a modification to the technique so that the optimization procedure results in lower maximum relative error compared to the ideal values. Simulation results for first order as well as higher order differentiators are given to illustrate the excellent performance of the proposed method.
The WLS algorithm results in lower value of maximum error. But this is quite large compared to the ideal values at lower frequencies. Thus the estimate of the differential has large error. If such an algorithm is used in instruments to measure differentials of varying quantities, the measured value may be very much off the mark. The discrepancy is more pronounced in case of DDs used for higher order differentiation. In this paper they proposed that the Relative error optimization algorithm distributes the absolute error such that the error at lower frequencies is lower and that at higher frequencies is higher. The algorithm results in a wider range of frequencies at which the relative error is smaller than any prescribed value, compared to the range obtained from WLS algorithm.

A paper titled "Genetic algorithm approach for designing 2-D FIR digital filters with 2-D symmetric properties" by Shian-Tang Tzeng proposed that the design of quadrant ally symmetric linear-phase 2-D FIR digital filters, a wide variety of linear-phase 2-D filter designs are proposed in this paper. It will start from the discussion of the symmetric properties to disclose their applications for designing linear-phase 2-D FIR digital filters. It is shown that there are 16 types of cases to be considered according to the symmetry/anti symmetry of 2-D sequences in both directions and their filter lengths (even or odd). The corresponding types of magnitude responses are tabulated into a complete table if these 2-D sequences are used to realize 2-D FIR digital filters. Also, the definition of quadrantal-plane, half-plane, and full-plane filters are described along with several numerical examples designed by the proposed genetic algorithm approach. In this paper, the symmetric properties of 2-D sequences and their applications for designing linear-phase 2-D FIR digital filters have been presented. It is shown that there are 16 types of cases to be considered according to the symmetry/antisymmetry of 2-D sequences in both directions and their filter lengths (even or odd).

The corresponding types of magnitude responses are tabulated into a complete table if 2-D sequences are used to realized 2-D FIR digital filters. Also, the definitions of quadrantal-plane, half-plane, and full-plane filters are described along with several numerical design examples illustrated by the proposed approach.

The digital filters with complex coefficients are useful in the application of processing analytic signals and complex envelops. They are also applied in single-sideband modulation systems. The genetic algorithm approach for designing such filters is developed in this paper. It is based on the evolution of real-valued population. The method is also optimal in the least-squares sense. Moreover, the proposed algorithm has several practical advantages such as simplicity and easy implementation with satisfactory performance. Two numerical design examples are shown to demonstrate the usefulness and effectiveness of this proposed approach.

Use of GA in Design of Digital Differentiator

First of all a second order transfer function is assumed as an integrator, then absolute relative error of this integrator with respect to ideal integrator is defined as a fitness function.

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Initial values of coefficients were decided. A set of possible solutions (individuals) is generated randomly from within a pre-defined range, they are represented as binary strings.

Then fitness function is applied on them and on the basis of their performance a fitness value is given to each individual. The reproduction operator is used to privilege good individuals and remove bad ones. The population size has been kept constant while creating new population. Two individuals are selected on the basis of their fitness value (higher fitness value has higher chance for selection). These individuals are known as parents. In the next step, crossover and mutation processes has been applied over parents to form new individuals (children). The main idea of crossover is that the children should be better than their parents. Crossover can

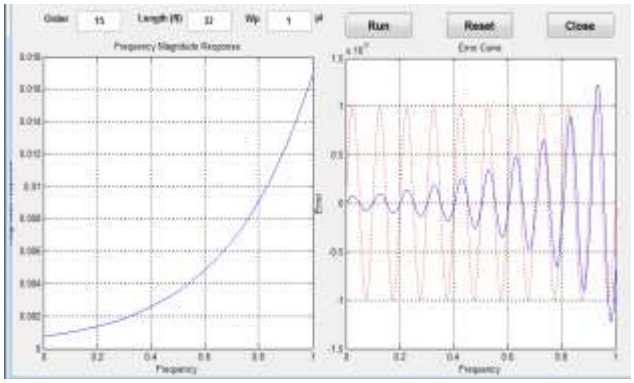

Table 1: Higher order digital differentiator design Examples

Differentiators	Fifteenth-order
Filter length	32
w_p: Highest	$\prod$

Digital Differentiator Applications In radars and sonars, the velocity and acceleration are computed from the position measurements using differentiation. Velocity is estimated by first order differentiation and acceleration by second order. The rate of liquid flow in a tank (which may be part of a chemical plant) is estimated from the derivative of the measured liquid level. In biomedical investigations, it is often necessary to obtain the first and higher order derivatives of the biomedical data, especially at low frequency ranges. For example in QRS complex detection in ECG.For geo-physical data processing, derivatives of the observation samples are usually needed for midband frequencies of the spectrum. Maximally flat differentiators near half Nyquist frequency are useful for this operation. The derivatives at high frequencies are useful for solving the problems of image restoration and image texture enhancement (to detect various features, like an edge, for example, of an object in the picture).The use of derivatives of various signals in control engineering (in auto-follow, servomechanism, robotics, artificial eye etc.) is also well known.

Fractional dimension is used to measure some real-world data such as coastline, clouds, dust in the air, and network of neurons in the body. The fractional dimension has been applied widely to pattern recognition and classification. Fractional Order Differentiators are used to exploit such real world issues. Fractional Order Differentiators are also used in bar code readers.

III. CONCLUSION

In this paper we have done survey on Low pass digital differentiator. We have used one of the optimization technique to optimize the error rate that is Genetic algorithm. We also surveyed on different types of digital differentiator along with low pass digital differentiator.

We found many applications of differentiators and mentioned in this paper. The future scope of this paper is to compare the same design using different optimization tehniues.

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