Variants of Genetic Algorithm for Efficient Design of Multiplier-Less Finite Impulse Response Digital Filter

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INTRODUCTION

Digital Signal Processing (DSP) is one of the most powerful technologies which have given appropriate shape to science, engineering and technology of twenty-first century. It has already found its significant applications in various areas like communication, medical imaging, speech and video processing, military surveillance, and so on. A perfect blending of sophisticated algorithms, powerful mathematical operations and specialized techniques has made this technological revolution to happen. As a matter of fact, DSP has become an inevitable part of modern technology in no times.

Digital filters are basic building blocks of any digital signal processing system of practical importance. Flexibility in the design of such filters has given the DSP techniques an extra edge over other alternatives. Entire set of digital filters are broadly categorized into Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters regardless of their frequency domain specifications. This classification is actually carried out on the basis of the internal architecture of the concerned filter. In comparison with its IIR counterparts, FIR filters are having desirable features like guaranteed stability, linear phase response and low coefficient sensitivity which have made this filter so popular for most of the wireless applications (Mitra, 2006). However, non-recursive FIR filters are heavily challenged by recursive IIR filters as it needs large number of arithmetic operations during its implementation. This in turn, limits the speed of the filter and consumes more power which makes it inappropriate for use in portable wireless devices like mobile phones, laptops, etc.

During implementation on high speed digital computer or DSP chips, each coefficient of digital filters is stored in registers of finite length and subsequently mathematical operations are performed by means of adders and multipliers. Considerable attention and effort have already been made by many of the researchers towards the design of low-power FIR filters. One of the most convenient ways to design such filters has been achieved by restricting each coefficient as sum of signed powers of two (SPT) terms. However, such restriction implicitly signifies that the coefficient space is bounded and limited by the coefficient word-length. This kind of representation substitutes the multiplication operation by simple addition and data shifting operation and finally leads multiplier-less hardware.

This article throws sufficient light on the design of power of two (POT) FIR filter exclusively. In connection to this, the design strategy has been regarded as an optimization problem because of the proper tuning of several interdependent parameters. A special class of evolutionary optimization algorithm, namely Genetic Algorithm (GA) along with some of its recent variants, has been taken into special consideration. Performances of the designed filters, as achieved with different algorithms, have been illustrated and properly analyzed. Towards the end of the article, directions for future research have been rightly pointed out.

BACKGROUND

Design of discrete coefficient digital FIR filters has drawn considerable attention of the researchers since last three decades. The very first article addressing

DOI: 10.4018/978-1-4666-5888-2.ch124

this issue was published in the year 1982 by Lim and his co-researchers who had proposed an idea of Mixed Integer Linear Programming (MILP) for designing finite word-length FIR filters (Lim, 1982). Similar work has shortly been facilitated by Weighted Least Square (WLS) method and local search technique in few years (Lim, 1983). These methods suffers from serious drawbacks in terms of computational complexity as the number of computation increases exponentially with the filter order and hence limits its application in synthesizing filters of higher length. Later on, scientists have thought to start with a given optimal filter solution and subsequently identified finite word-length solution in the neighborhood of an optimal solution that will minimize the computational cost. This simplest scheme of truncating the coefficients to a fixed-bit representation has not come up with a reliable solution since the frequency response of these filters seems to be significantly affected by the process of coefficient quantization.

Realization of discrete coefficient FIR filter is largely an optimization problem which makes a trade-off between the supremacy of the achievable design and the resulting hardware cost. In this connection, the previous century has gifted us a number of new optimization algorithms which are more commonly influenced either by genetic evolution or by social behavior of creatures. Algorithms which are based on the natural selection and genetics are collectively known as Genetic Algorithms (GAs) and have widely been employed in a large number of optimization problems of particular interest. The most attractive features of these algorithms are that they can discard local sub-optimal solution, obtained from gradient-based algorithms, in favor of more promising global solutions. Consequently GAs have been used efficiently for solving wide variety of science and engineering problems ranging from pattern recognition, robotics to electrical power systems, control systems, bioinformatics, etc.

Signal processing of various kinds has also been extensively influenced by GAs in recent times. Accordingly, a number of articles have been reported in the literature illustrating the application of GAs in designing digital filters of various kinds. In this regard, several works have been reported in some of the recent articles (Chauhan, 2011; Dey, 2010; Barros, 2006; Ahmad, 2006; Cemes, 1993; Suckley, 1991). This article throws sufficient light on the efficient design of multiplier-less FIR filter by different variants of GA such as micro Genetic Algorithm (μGA) (Senecal, 2000), modified micro Genetic Algorithm, orthogonal Genetic Algorithm (OGA) (Ahmad, 2006).

NOTION OF MULTIPLIER-LESS FIR FILTER

Digital FIR filter is always characterized by the system function $H(z)$ which is related to its impulse response $h(n)$ as follows (Mitra, 2006; Antoniou, 2001):

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

where 'N' indicates the length of the filter. The frequency response of such a filter is given by (Mitra, 2006; Antoniou, 2001):

$$H(e^{j\omega}) = \sum_{n=0}^{N-1} h(n) Trig(n,\omega) \tag{2}$$

where $Trig(n,\omega)$ is a trigonometric function that depends upon the type of the filter used. Specifically, for a linear-phase symmetric real FIR filter of odd length, corresponding frequency response assumes a form (Mitra, 2006):

$$H(e^{j\omega}) = h(0) + \sum_{n=1}^{(N-1)/2} h(n) cos(\omega n) \tag{3}$$

It has been a common practice to represent the transfer function of any linear-phase FIR filter as a mirror-image polynomial. The system function of such a filter can also be decomposed into a cascade of second and fourth order sub-filters in which the formulation of $H_k(z)$ depends entirely on the position of zeros in the z-plane as shown below:

$$H(z) = \prod_{k=1}^{\mathbb{K}} H_k(z) \tag{4}$$