



International Journal of Advanced Research in Computer Science and Software Engineering

Research Paper

Available online at: www.ijarcsse.com

Evolutionary Approach for Filter Design: a Review

Er. Karamjeet Singh

ECE Department & BBSBEC, Fatehgarh Sahib
India

Gurpreet Kaur

ECE Department & BBSBEC, Fatehgarh Sahib
India

Abstract—Filtering has been an enabling technology and has found ever-increasing applications. There are two main classes of digital filters: finite impulse response (FIR) filters and infinite impulse response (IIR) filters. FIR filter can be guaranteed to have linear phase and are always stable filters, so FIR filters is widely applicable. Design of different types of digital FIR filter is of paramount significance in various Digital Signal Processing (DSP) applications. Different optimization techniques can judiciously be utilized to determine the impulse response coefficients of such a filter. Some evolutionary algorithms are Genetic Algorithm (GA), Particle Swarm Optimization (PSO) or Differential Evolution (DE) techniques [1]. This paper gives the review of various evolutionary optimization techniques used for the design of digital FIR filters.

Keywords—FIR filter; differential evolution algorithm; REMEZ algorithm; Standard Particle Swarm Optimization algorithm

I. Introduction

Filtering is a process by which the frequency spectrum of a signal can be modified, reshaped, or manipulated according to some desired specifications. There are two types of digital filters: finite impulse response (FIR) filters and infinite impulse response (IIR) filters. Compared to IIR filters, the main advantages of FIR filters are as follows: (1) finite impulse response, (2) easy to optimize, (3) linear phase, (4) they are always stable filters. FIR filters has been widely applied to the image processing, data transmission, signal processing etc. There are many traditional methods which design FIR filters, such as window function, Frequency Sampling, least mean square error etc [2]. Applications such as digital television and videoconferencing require high data-processing speeds and throughputs. They cannot depend upon general programmable digital-signal-processing cores. Instead, they need custom-specific hardware, designed for constant coefficients. The main operations in all data processing cores are filtering and convolution, which involve multiplication of filter coefficients with the input digital data. Hence, minimizing the number of multiplications per coefficient optimizes the filter hardware in terms of area and power consumption [3]-[4]. In general, filter multiplications are performed by shift and-add method, without any actual multipliers. Hence the filter is said to be multiplierless. Fewer multiplications can be achieved, if the number of SPT terms in the coefficients is minimized, because each non-zero bit contributes to one multiplication [5]. This minimization can be done by any numerical algorithm, to optimize the coefficients and at the same time ensure that the resulting frequency response matches the desired specifications, with minimum allowable error margins [6]. REM algorithm is a popular algorithm of the same type, and has been used as a standard reference to compare with the MDE algorithm. The main disadvantage of numerical algorithms is that they impose a lot of conditions such as differentiability and monotonicity on the inputs. Also, all optimization problems cannot get represented or bounded in polynomial form. There is another set of techniques known as the heuristic techniques which do not make use of rigorous mathematical evaluations to solve the problem. Instead, they make use of “experience-based learning”, in which, for every particular problem, the algorithm is developed by running it for a variety of inputs and matching the outputs with the expected values [7]. Each time, the control parameters of the algorithm are altered empirically, to reach the target output. They are “Rule-of-thumb” techniques, which converge faster towards the solution, because of their “greedy” approach to arriving at a solution, i.e. to reach the solution they always take those paths which are beneficial.

II. Different evolutionary algorithms

A. DE algorithm:

DE is a powerful non-deterministic algorithm, which converges towards a solution, by continuously refining an initial search space. After every round of refinement, the coefficients are tested for their “fitness” to survive, and whether they can form a part of the final solution. The set of search space elements, after each refinement, is said to form one generation. The application of DE algorithm in digital FIR filter design is now briefly explained. An initial search space of probable coefficients is constructed. Four row vectors X_1 , X_2 , X_3 , and X_4 are formed by randomly choosing numbers from this space. The size of the vectors is known from the order of the filter. Each vector is a probable coefficient set, subjected to

improvisation. Three vectors, say X2, X3 and X4, are then combined in a systematic way to generate a fresh vector V. The vector X1, called the parent, is mixed with the vector V, to generate a child vector, say U. Depending on how much it deviates from the desired response, the coefficient vector X1 may be retained, or replaced by the vector U. The elements of search space are refined continuously by running the algorithm for a large number of generations. Finally, after several iterations of the above algorithm, all these vectors will yield very good frequency responses and any appropriate vector may be taken as the final solution. The major steps in a DE algorithm for FIR filter design are Initialization, Mutation, Recombination, Evaluation and Selection. Here, the main objective of the iterations is to generate the filter coefficients, which yield the desired frequency response, with allowable deviations. Then, the coefficient set having minimum number of SPT terms in them are chosen, to result in less number of multiplications [8]. One of the main features of DE is the less number of initial parameters and empirical values to be supplied by the user. The parameters are search population size (NP), number of generations, crossover ratio (CR) and mutation weight factor (F). In comparison to other heuristics, DE gives large importance to mutation, due to which new vectors can be generated from existing population members. Primitive DE algorithms were extremely slow, involved large number of control parameters and depended much upon the initial population members. By creating new mutated vectors, convergence speeds improved, and also led to improved diversity in the search population. After mutation, the process of retaining or eliminating the new vector is said to be an elitist process, because it ensures the preservation of the best possible individuals for future generations. The algorithm is also said to be “greedy” because of its tendency to continuously move “downhill” towards achieving minimum cost function, in every iteration.

B. REMEZ Algorithm:

This is a general iterative algorithm, which will approximate a given complicated mathematical equation to the best possible polynomial. The new polynomial should resemble the main function, with minimum deviation from the actual specifications. The given frequency specifications are mapped on to a polynomial and solved using Remez Algorithm. The coefficients for the FIR filter are generated from Remez algorithm using the Remez function in MATLAB [9]. The Remez algorithm first considers a function “f” to be approximated. This is written as:

$$f(\omega) = C_0 + C_1\omega^1 + C_2\omega^2 + \dots + C_{M-1}\omega^{M-1} \quad (1)$$

The values of $f(\omega)$ at M values of ω yield M simultaneous equations, which are solved to get the values of the coefficients, C0, C1....., CM-1. These coefficients do not guarantee minimum deviation of the approximated function from the actual values. Let the function evaluate to a value A, at these coefficient values.

$$Deviation = || D(\omega) - A(\omega) || \quad (2)$$

Here D (w) is the desired frequency response and A (w) is the actual response obtained. If the deviation at every frequency w is less than the maximum allowable deviation, then these coefficients are the most optimum filter coefficients. Else, the frequency values are replaced with the new coefficient values and the iterations are repeated.

C. Standard Particle Swarm Optimization Algorithm:

PSO, originally proposed by J. Kennedy and R. Eberhart in 1995[10,11], is a new global search technique. The underlying motivation for the development of PSO algorithm was social behavior of animals such as bird flocking, fish schooling, and swarm theory. Like GA, PSO is also a population based random search technique and outperforms GA in many practical applications, particularly in non-linear optimization problems. In the standard PSO model, each particle represents a potential solution within the search space and it is characterized by a position, a velocity and a record of its past performance. At each cycle, the object function for each particle was evaluated with respect to its position. The obtained value measured the quality of the particles. In PSO algorithm, particles fly through the search space influenced by two factors: a) the best partial position of the particle recorded in its history; b) the best global position experienced by any particle from the whole population. The particle moves according to the following equation:

$$V_i[t+1] = w \times V_i[t] + c_1 \times \text{rand}(\cdot) \times (P_i - X_i) + c_2 \times \text{Rand}(\cdot) \times (P_g - X_i) \quad (3)$$

$$X_i[t+1] = X_i[t] + V_i[t+1] \quad (4)$$

Where $V_i = [v_{i1}, v_{i2}, \dots, v_{in}]$ is the velocity of ith particle; $X_i = [x_{i1}, x_{i2}, \dots, x_{in}]$ is the position; P_i is the best previous position of particle i called pbest; P_g is the position among all the particles in the population and called gbest; c1 and c2 are acceleration factors that determine the relative pull for each particle toward pbest and gbest; rand(·) are random functions in the range of [0,1]; w is the inertia weight used to control global exploration and local exploitation of the particles, and is usually varied linearly from 0.9 to 0.4 in a decreasing order throughout the simulation. The decreasing formula given by:

$$W = W_{max} - g \times \frac{W_{max} - W_{min}}{T_{max}} \quad (5)$$

Where g is the generation at present, and T_{max} is the max termination generation. Particle swarm iterates according to above equation and finally gives a solution until the termination condition is reached.

III. CONCLUSION

Different evolutionary algorithms has been applied for the design of FIR filters. From the previous study, it has been proved that the new evolutionary algorithms are fit for the design of FIR filters with higher orders. It would perform much better and faster to obtain approximation of the filter coefficients.

Future Work:

Further research is required to improve the new evolutionary algorithm and to be integrated with evolvable hardware.

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