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Low Pass Filter Design Using Bacterial Foraging with Particle Swarm Optimization

Rupinder Kaur[1], Pooja Sharma[2]

[1]Department of ECE, Galaxy Global Group of Institution, Ambala, India (M.Tech Student)
[2]Department of ECE, Galaxy Global Group of Institution, Ambala, India (Assistant Professor)

Abstract: *This article present a study of optimal linear phase digital low pas filter using Bacterial Foraging and Particle Swarm Optimization. This combine approach of BFO and PSO provide better solution to solve the optimization problem of digital filter. FIR filter design is a multimodal optimization problem. To find best optimal solution, various optimization techniques like Real Code Generation algorithm (RGA), Swarm Intelligence Technique (SI), Bacterial Foraging and Tabu Search Optimization (BFTS) etc are used. Optimization is the process used for minimized or optimized the conflicts present in design of any filter.*

Keywords: *PSO (Particle Swarm Optimization), BFO (Bacterial foraging Optimization), EColi (Escherichia Coli), FIR (Finite Impulse Response), IIR (Infinite Impulse Response)*

1. Introduction

With the evolution of new technologies, Intensive researchers have been made on digital signal processing (DSP) and great advances in VLSI technologies have had a great importance in Electronic and Communication Engineering/Control Industry. Various techniques have been made for design of filters. A filter is a frequency selective network or system that changes the amplitude-frequency and phase- frequency response of a signal in a desire manner. Basically filter perform two functions are signal separation and signal restoration. When signal has been combined with interference, noise and other unwanted signals then signal separation is needed. When signal is distorted in some other way then signal restoration is needed.

A digital filter is a selective network that operates on a digital input and by performing implementation on this digital input using some digitized hardware and software, digital output is produced. On the other hand, analog filter perform action on a analog input. In analog filters accuracy and stability is less due to limitation imposed by analog components such as resistors, capacitors and combination of both. Complexity of analog filter is also large. So that digital filters are used comparatively with analog filters. For the design of any digital filter, by substituting the value of pass band frequency, Stop band frequency, pass band ripple, stop band attenuation, filter order, sampling frequency in a desired manner, we can get value of filter coefficient h(n) from which we can find filter response.

2. Bacterial Foraging Optimization

Bacterial foraging is a population based optimization technique developed by Prof. K. M. Passino in 2001 [1], inspired by social foraging behavior of *Escherichia Coli* which is used to solve optimization problems of filters. BFO algorithm based on foraging strategies of E Coli bacterium cells that tend to eliminate poor foraging strategies. BFO formulate the foraging behavior by bacteria such that it maximizes their energy intake per unit time. It consists of mainly four steps are chemotactic, swarming, reproduction and elimination/dispersal respectively. Natural selection of those bacteria that have strong foraging strategies and elimination of those that have poor foraging strategies occurs.

2.1. Chemotactic

The movement of E Coli bacteria in optimal direction by a fixed distance or height is accomplished with the help of locomotory organelles known as flagella by chemotactic movement in two ways. If a bacterium moves in same direction from previous one is called swimming and if bacterium moves in an absolutely different direction from previous one is called tumbling. Movement of Flagella in anticlockwise direction helps the bacteria to swim at very fast rate. Thus swimming and tumbling together known as chemotactic.

2.2. Swarming

When bacterium find its optimal position, it is desire that optimum bacterium should try to attract other bacteria by passing information about the nutrient concentration (optimal point) so that all the bacteria together converge the desired location very rapidly. Depending on the relative distance of each bacterium from fittest bacterium, a penalty function is added to original optimization function to find position of new bacteria. When all bacteria find their optimal position then penalty function becomes zero.

2.3. Reproduction

After evolution through several chemotactic steps and swarming, original set of bacteria is allowed to be reproduced. Reproduction is a conjugation process in which bacteria is split into two identical bacteria. Reproduction is depends on health of bacteria. The least healthy bacteria from total population are eventually eliminated where as healthy bacteria will be split in two parts which are place at same location. During this reproduction process concentration of total bacteria remains constant.

2.4. Elimination/dispersal

During evolution process, elimination of set of bacteria is occurs and dispersed them into new environment. The new position of bacteria results in drastic alteration of biological process of evolution. The concept behind this process is to place a newer set of bacteria nearer to optimal location to avoid premature trapping into local optima instead of global optima known as stagnation.

3. PARTICLE SWARM OPTIMIZATION

PSO is a evolutionary optimization technique with implicit parallelism developed by Dr. Russel Eberhart & Dr. James kennedy [2] in 1995 desired by bird flocking and fish schooling which can easily handled with non differential objective functions. PSO makes few or no assumptions about the problem being optimized and have capability of searching very large spaces of candidate solutions. Bird flocking optimize a certain objective function. A convenient solution for any problem can be evolved by set of potential solutions. Each particle searches for optimal position by changing its velocity according to rules by behavioral model of bird flocking with in a search space. Position of each particle provide a optimize solution. The define search space is shared by each individual.

In PSO algorithm each individual is called particle and total population is called swarm. Particles are assumed to be volume less and are subjected to movement in multi dimensional space. There is no restriction for particles to hold at the same point in n-dimensional space but in any case their individuality shall be preserved. Development of PSO is through simulation of bird flocking in multi dimensional space. Each particle vector i.e. bird knows its best position called pbest and this position correspond to personal experience of each particle vector. Each particle vector knows best value in group gbest among pbest. Each particle vector finds its best position and consists of components or strings as required number of normalized filter coefficients, depends on order of filter.

4. BACTERIAL FORAGING WITH PARTICLE SWARM OPTIMIZATION

The social foraging behavior of E. Coli bacteria [3] and implicit parallelism behavior of swarm of birds or collective intelligence [4] of a group with limited capability is used to solve non linear optimization problem in designing of digital filters. This classical combined algorithm has great importance in solving real world optimization problems.

The PSO is initialized with assigning random position and velocities to each bacterium. Particles have ability to move in any direction in n-dimensional space. A fitness/cost function is evaluated using this initial velocity and position. A each define time step, new function is evaluated with new coordinates based on previous value. Velocity and position of particle with each time step given as follow:

$$V_{id}(t+1) = w.V_{id}(t) + C_1.\varphi_{1.}(P_{id}(t) - X_{id}(t)) + C_2.\varphi_{2.}(P_{gd}(t) - X_{id}(t))$$

$$X_{id}(t+1) = X_{id}(t) + V_{id}(t+1)$$

On the other hand, BFOA is based on searching and foraging decision capability of E. Coli bacteria. The coordinate of each bacterium represents an individual solution. A set of trial solution converges towards finding optimal solution. Each bacterium continuously performing its chemotactic movement until bacterium finds its best fitness value (positive nutrient gradient). After undergoing chemotactic steps, each bacterium gets mutated by PSO. PSO have capability to exchange social information, unit length direction of tumble behavior is generated. If bacteria are move randomly in any direction then this lead to delay to reach the optimal solution. In BF-PSO algorithm, tumble behavior of bacteria can be decided by global best position and best position of bacterium. It provides fast convergence speed compared with conveniently bacterial foraging and particle swarm optimization. The proposed BF-PSO algorithm to search for optimal value of parameters described as follow (Krone, 2008; Biswas, Dasgupta, Das, Abralam, 2007; E. S. Ali, S. M. Abd-Elazim, 2013[5])

[Step 1] Initialization of following parameters

d : Dimension of search space to be optimized,

D : Total population of bacteria,

N_C : Number of chemotactic steps,

N_{re} : Number of reproduction steps,

N_{ed} : Number of elimination dispersal steps,

P_{ed} : Probability of elimination dispersal steps,

$C(i)$: Step size taken by tumble in random direction,

W : Inertia weight,

m : Swim Length,

C_1, C_2 : The weighting factor,

φ_1, φ_2 : Uniform random number within range [-1 1],

$\theta(i, j, k)$: Position of i^{th} bacterium, in j^{th} chemotactic, k^{th} reproduction step,

V_i : Velocity vector of i^{th} bacterium.

[Step 2] Update the following

$J(i, j, k)$: Fitness value or cost value of i^{th} bacterium in j^{th} chemotactic, k^{th} reproduction.

θ_{g_best}: Position vector of the best position found by all bacteria.

$J_{best}(i, j, k)$: Fitness of best position found so far

[Step 3] Reproduction loop: $k = k + 1$

[Step 4] Chemotactic loop: $j = j + 1$

[Sub step i] For i = 1, 2, 3… D, take a chemotactic step for bacterium i as follow:

[Sub step ii] Compute fitness function $J(i, j, k)$

[Sub step iii] Save $J_{last} = J(i, j, k)$ to this value and find a better cost via a run

[Sub step iv] Tumble: Generate a random vector $\triangle(i) \in R^d$ with each element of $\triangle_m(i)$, m=1, 2, 3 ….D

[Sub step v] Let

$$\theta(i, j+1, k) = \theta(i, j, k) + C(i).\frac{\triangle(i)}{\sqrt{\triangle T(i).\triangle(i)}}$$

[Sub step vi] Find $J(i, j+1, k)$

[Sub step vii] Swim: Consider only i^{th} bacteria will swim while other not moves.

a) Initialize Swim counter m=0

b) While $m < D_s$

- m= m+1
- If J (I, j+1, k)< J_{last}

  Let J_{last} = J (I, j+1, k) and let

$$\theta(i, j+1, k) = \theta(i, j, k) + C(i).\frac{\triangle(i)}{\sqrt{\triangle T(i).\triangle(i)}}$$

  Use this θ (i, j+1, k) to compute the new △ (i, j+1, k)

- Else, m= D_s [End of while loop]

[Sub step viii] Mutation with PSO operator

For i= 1, 2, 3 …D

a) Update θ_{g_best} and J_{best} (i, j, k)
b) Update position and velocity of d-th coordinate of the ith bacterium according to following rules

$$V_{id}(New) = w.V_{id}(New) + C_1.\varphi_1.(\theta_{g\_best} - \theta_d(i, j+1, k)_{old})$$

$$\theta_d(New) = \theta_d(i, j+1, k)_{old} + V_{id}(New)$$

[Step 6] Let D_r = D/2

The half of the bacteria with low cost function will survive and split into two parts

While other half will die.

[Step 7] If K<N_{re}, go to step 1.

5. Related Work

The multiobjective design of digital filters using the powerful Taguchi optimization technique is considered in this paper. At start up, only magnitude response has been considered in the optimization task. The resulting filter was good in terms of this characteristic while it showed awful dynamic and phase performance. Next, the dynamic properties were included in the optimization algorithm to solve a multi objective task. The Taguchi optimization method has succeeded in attaining the optimal design in terms of the previous requirements by achieving a compromise between them. The optimized filter has been tested and it showed good performance with required practical characteristics [6].

Spiral optimization technique tool is a Meta heuristic technique inspired by the dynamics of spirals. It is characterized by its robustness, immunity to local optima trapping, relative fast convergence and ease of implementation. The objectives of filter design include matching some desired frequency response while having minimum linear phase; hence, reducing the time response. The results demonstrate that the proposed problem solving approach blended with the use of the spiral optimization technique produced filters which fulfill the desired characteristics and are of practical use [7].

This paper establishes methodology for the robust and stable design of infinite impulse response (IIR) digital filters using hybrid differential evolution method. Differential Evolution (DE) is undertaken as a global search technique and exploratory search is exploited as a local search technique. Through simulation it has been shown that the DE method works well with an arbitrary random initialization and it satisfies prescribed amplitude specifications consistently. The proposed DE approach for the design of digital IIR filers allows each filter, whether it is LP, HP, BP, or BS filter, to be independently designed. The proposed DE is very much feasible to design the digital IIR filters, particularly with the complicated constraints. Parameters tuning still is the potential area for further research. The unique combination of exploration search and global search optimization method that is DE provided by the two types of algorithms yields a powerful option for the design of IIR filters [8].

In this paper, a novel opposition-based harmony search (OHS) algorithm is applied to the solution of the constrained, multimodal FIR filter design problem, yielding optimal filter coefficients. Comparison of the results of PM, RGA, PSO, DE, and OHS algorithm has been made. It is revealed that OHS has the ability to converge to the best quality near optimal solution and possesses the best convergence characteristics in moderately less execution times among the algorithms. The simulation results clearly indicate that OHS demonstrates better performance in terms of magnitude response, minimum stop band ripple, and maximum stop band attenuation with a very little deterioration in the transition width. Thus, OHS may be used as a good optimizer for obtaining the optimal filter coefficients in any practical digital filter design problem of digital signal processing systems [9].

In this paper, an improved DE algorithm combined with HS has been proposed, which not only increases the population's diversity, but also avoids the parents being selected from just two populations in one generation. Although the DE algorithm has reached an impressive state, the enhancements of the population is still one open problem. DEHS is a rotationally invariant way to generate more potential points without increasing the number *Np* of population members. On one hand, DEHS can use the pitch-adjustment to improve the individuals that get better optimal results. On the other hand, DEHS makes a new vector after considering all existing vectors rather than considering only two (parents) as in DE. So, compared with standard DE, DEHS has similar capacity with DE on the usual test functions and the low-dimensional and multi-modal functions, but has better ability than DE on high-dimensional functions. In our future work, we will consider how to improve the algorithm's characteristics, how to enhance the population's diversity but not increase the population, moreover, to heighten the algorithm's performance and decrease the running time [10].

6. CONCLUSION

This paper represents a comprehensive review of Bacterial Foraging and Particle Swarm Optimization algorithm used to solve numerical optimization problem in designing of low pass digital filter. In comparison with individual BFO and PSO approach, this combined technique of BF-PSO outperforms in accuracy of filter response as well as convergence speed and can be used in other related design problems.

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