

Big Bang–Big Crunch Optimization Algorithm for Linear Phase Fir Digital Filter Design

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Abstract - The Big Bang–Big Crunch (BB–BC) optimization algorithm is a new optimization method that relies on the Big Bang and Big Crunch theory, one of the theories of the evolution of the universe. In this paper, a Big Bang–Big Crunch algorithm has been used here for the design of linear phase finite impulse response (FIR) filters. Here the experimented fitness function based on the mean squared error between the actual and the ideal filter response. This paper presents the plot of magnitude response of FIR filters and error graph. The BB–BC seems to be promising tool for FIR filter design especially in a dynamic environment where filter coefficients have to be adapted and fast convergence is of importance.

Key words - Big Bang–Big Crunch, optimal linear phase magnitude response, Error function, MATLAB.

I. INTRODUCTION

A filter is often a frequency selective device which passes signals of certain frequencies and blocks or attenuates signals of other frequencies. Filters could be analog or digital. Analog filters use electronic components such as resistor, capacitor, transistor etc. to perform the filtering operations. These are mostly used in communication for noise reduction, video/audio signal enhancement etc. In contrast, digital filters use digital processors which perform mathematical calculations on the sampled values of the signal in order to perform the filter operation. Digital filter can be implemented by means of software (computer program), dedicated hardware, or a combination of software and hardware. Software digital filter may be implemented using low-level language on a general-purpose digital signal-processing chip or in terms of a high level language on a personal computer or workstation. At the other extreme, hardware digital filters can be designed using a number of highly specialized interconnected VLSI chips.

Traditionally, different techniques exist for the design of digital filters. Each method has its own limitations such as Windowing methods do not allow sufficient control of the frequency response in the various frequency bands and other filter parameters such as transition width. Designer always has to compromise on one or the other of the design specifications. So, evolutionary methods have been implemented in the design of digital filters, to design with better parameter control and to better approximate the ideal filter. Since population based Stochastic search methods have proven to be effective in multidimensional

nonlinear environment; all of the constraints of filter design can be effectively taken care of by the use of these algorithms.

Various filter parameters which come into picture are the stop band and pass band normalized frequencies (ω_p , ω_s), the pass band and stop band ripple (δ_p and δ_s), the stop band attenuation and the transition width. These parameters are mainly decided by the filter coefficients. Significance of these parameters in actual filters with respect to ideal filter is illustrated in Fig. 1. In any filter design problem, some parameters are fixed while others are determined.

In this paper, BB–BC applied in order to obtain the actual FIR filter response as close as possible to the ideal response.

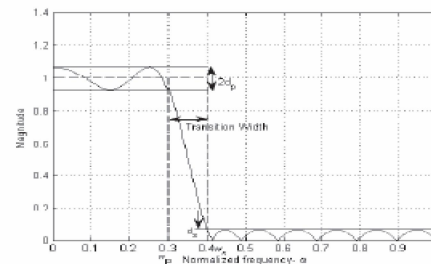


Fig. 1. Ideal and Actual filter Magnitude response showing passband and stopband ripples and transition band in actual filter.

Previously, computational Intelligence based techniques such as neural networks, particle swarm optimization (PSO) and genetic algorithms (GA) have been implemented in the design of digital filters. One such approach using neural networks has been described in [1]. Use of PSO and GA in the design of digital filters is described in [2]. Also, use of PSO in the design of frequency sampling finite impulse response (FIR) filter has been described in [3].

A new optimization method relied on one of the theories of the evolution of the universe namely, the Big Bang and Big Crunch theory is introduced by Erol and Eksin [06] which has a low computational time and high convergence speed.

II. FIR DIGITAL FILTER DESIGN

Finite impulse response digital filters of length N are described in the time domain by the following equation:

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

corresponding frequency response of the FIR filter

is given as:

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

The transfer function of FIR filter in z -domain based on its frequency response is a polynomial:

$$H(z) = h(0) + h(1)z^{-1} + \dots + h(N-1)z^{-(N-1)}$$

i.e. $H(z) = \sum_{n=0}^{N-1} h(n) z^{-n} \quad (3)$

In case of causal transfer function, the phase distortion can be avoided by ensuring a linear-phase characteristic in the frequency band of interest. The linear-phase relationship can be guaranteed if the impulse response is either symmetric i.e.

$$h(n) = h[N-n], \quad 0 < n < N \quad (4)$$

Or anti-symmetric, i.e.

$$h(n) = -h[N-n], \quad 0 < n < N \quad (5)$$

The process of designing FIR filters is to select a set of filter coefficients $h(n)$, so that the frequency response $H(e^{j\omega})$ approximates a desired frequency response $D(e^{j\omega})$ with a minimum error function $E(e^{j\omega})$. The frequency response error function is defined as:

$$\|E(e^{j\omega})\| = \|H(e^{j\omega}) - D(e^{j\omega})\| \quad (6)$$

Where, the symbol $\| \cdot \|$ represents the approximation criteria.

III. BIG BANG-BIG CRUNCH (BB-BC) OPTIMIZATION ALGORITHM

The BB-BC method developed by Erol and Eksin [6] in 2006, consists of two phases: a Big Bang phase, and a Big Crunch phase. In the Big Bang phase, candidate solutions are randomly distributed over the search space. Similar to other evolutionary algorithms, initial solutions are spread all over the search space in a uniform manner in the first Big Bang. Erol and Eksin [6] associated the random nature of the Big Bang to energy dissipation or the transformation from an ordered state (a converged solution) to a disorder or chaos state (new set of solution candidates). Randomness can be seen as equivalent to the energy dissipation in nature while convergence to a local or global optimum point can be viewed as gravitational attraction. Since energy dissipation creates disorder from ordered particles, we will use randomness as a transformation from

a converged solution (order) to the birth of totally new solution candidates (disorder or chaos) [6]. The Big Bang- Big Crunch (BB-BC) Optimization method similarly generates random points in the Big Bang phase and shrinks these points to a single representative point via a center of mass in the Big Crunch phase. After a number of sequential Big Bangs and Big Crunches where the distribution of randomness within the search space during the Big Bang becomes smaller and smaller about the average point computed during the Big Crunch, the algorithm converges to a solution.

The proposed method is similar to the GA in respect to creating an initial population randomly. The creation of the initial population randomly is called the Big Bang phase. In this phase, the candidate solutions are spread all over the search space in a uniform manner [6]. The Big Bang phase is followed by the Big Crunch phase. The Big Crunch is a convergence operator that has many inputs but only one output, which is named as the ‘‘center of mass’’, since the only output has been derived by calculating the center of mass. Here, the term mass refers to the inverse of the merit function value [14]. The point representing the center of mass that is denoted by ‘ X_c ’ is calculated according to:

$$X_c = \frac{\sum_{i=1}^N (1/f_i) x_i}{\sum_{i=1}^N (1/f_i)} \quad (7)$$

Where ‘ X_i ’ is a point within an n -dimensional search space generated, ‘ f_i ’ is a fitness function value of this point; ‘ N ’ is the population size in Big Bang phase. The convergence operator in the Big Crunch phase is different from ‘exaggerated’ selection since the output term may contain additional information (new candidate or member having different parameters than others) than the participating ones, hence differing from the After the Big Crunch phase, the algorithm creates the new solutions to be used as the Big Bang of the next iteration step, by using the previous knowledge (center of mass). This can be accomplished by spreading new off-springs around the center of mass using a normal distribution operation in every direction, where the standard deviation of this normal distribution function decreases as the number of iterations of the algorithm increases:

$$X_{new} = X_c + l \cdot r / k \quad (8)$$

Where ‘ X_{new} ’ stands for center of mass, l is the upper limit of the parameter, r is a normal random number and k is the iteration step. Then new point X_{new} is upper and lower bounded.

The BB-BC approach takes the following steps [6]:

Step 1: Form an initial generation of N candidates in a random manner. Respect the limit of the search space.

Step 2: Calculate the fitness function values of all the candidate solutions.

Step 3: Find the center of mass according to (7). Best fitness individual can be chosen as the ‘‘Center of mass’’.

Step 4: Calculate new candidates around the center of mass by adding or subtracting a normal random number whose value decreases as the iterations elapse of using (8). **Step 5:** Return to Step 2 until stopping criteria has been met.

Basic flowchart for BB-BC optimization method and detail flowchart showing the design of FIR digital filters using BB-BC algorithm are given in fig. 2 and fig. 3 respectively.

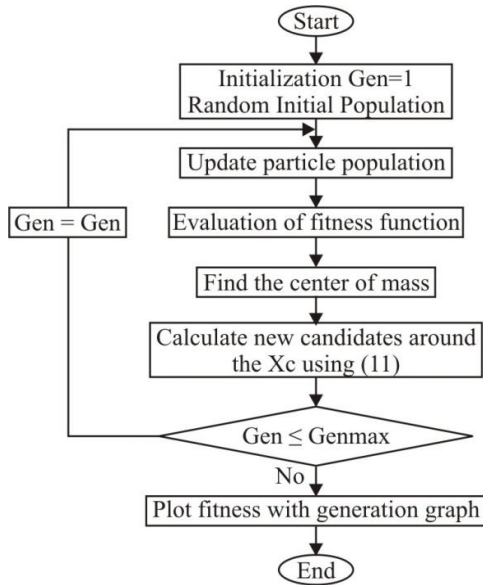


Fig. 2. BB-BC (FIR filter design problem) computational procedure.

IV. BIG BANG-BIG CRUNCH (BB-BC) BASED DIGITAL FILTER DESIGN

Consider an FIR filter with the following transfer function:

$$\frac{Y_n}{X_n} = a_0 + a_1 z^{-1} + a_2 z^{-2} + \dots + a_n z^{-n} \quad (9)$$

Now for (9), the numerator coefficient vector $\{a_0, a_1, a_2, a_3, \dots, a_n\}$ is represented in 'n' dimensions. The particles are distributed in a D dimensional search space, where $D = n$. The position of the particles in this D dimensional search space represents the coefficients of the transfer function. For the problem at hand, the FIR filter is chosen to be of a linear phase type. So its coefficients are matched. Thus the dimension of the problem reduces by a factor of 2. The D/2 coefficients are then flipped and concatenated to find the required D coefficients [2]. The detail operations in the filter design have been summarized in the flowchart in Fig. 3.

Fitness function:-

For the design of linear-phase FIR filter with least-p error criterion, the filter coefficients can be found, such that, the error measure is minimized. The least-p error

criterion minimizes the integral of the pth power of the weighted error function ϵ given by:

$$\epsilon = \int_{-\pi}^{\pi} |F(\omega) - D(\omega)|^p \omega \, d\omega \quad (10)$$

For pass band attenuation δ_p and stop band attenuation δ_s , the weighting function $F(\omega)$ in eq. (10) is given by:

$$F(\omega) = \begin{cases} 1 - \delta_p / \delta_s, & \text{in the pass band} \\ 0, & \text{in the stop band} \end{cases} \quad (11)$$

and desired magnitude response $D(\omega)$ in eq.(10) for the low pass filter is given by:

$$D(\omega) = \begin{cases} 1, & \text{in the pass band} \\ 0, & \text{in the stop band} \end{cases} \quad (12)$$

Since, type I i.e. odd symmetric linear phase FIR filter is designed in this paper, so $A(\omega)$ for this type of filter is expressed as:

$$A(\omega) = \sum_{k=0}^M a(k) \cos(\omega k) \quad (13)$$

Where, $a(0) = h(M)$ and $a(k) = 2h(M-k)$, for $1 \leq k \leq M$. $M = (N-1)/2$ and $N =$ order of filter.

In practice, the integral error (eq.10) is approximated by a finite sum given by:

$$\epsilon = \sum_{i=1}^k |F(\omega_i) [A(\omega_i) - D(\omega_i)]|^p \quad (14)$$

Where $\omega_i, 1 \leq i \leq k$ is suitable chosen grid of digital angular frequencies for the range $0 \leq \omega \leq \pi$. Usually, p is taken as a value 1 to 6. The conventional least squares criterion uses $p=2$.

In this paper, BB-BC optimization method is applied for the design of Type-I FIR filter, for which the expression for the least-p error criterion is expressed as:

$$\epsilon = \sum_{i=1}^k |F(\omega_i) [\sum_{k=1}^M a(k) \cos(\omega_i k) - D(\omega_i)]|^p \quad (15)$$

Where, $M = (N-1)/2$ and $N =$ length of filter.

A similar formulation can be derived for the remaining three types of linear-phase FIR filters. This design approach can be used to design a linear-phase FIR filter with arbitrarily shaped desired response.

Step for obtaining filter coefficients using BB-BC Optimization method:

The implementation of BB-BC algorithm for optimizing the filter coefficients is given as follows:

- 1) Define search space, population size L, order of filter N, stop band frequency and pass band frequency.
- 2) For type-I, low pass FIR filter design, the particle is $X(k)$ so generate random particles position which is the vector containing 'L' rows and $(N-1)/2$ columns.

L is population size. Thus the filter coefficient vector $a(k)$ represented by $X(k)$ is:

$$X_j = [X_{j1}, X_{j2}, \dots, X_{jNC}] \quad (16)$$

Where $j=1,2,3,\dots,L$ and $NC=(N-1)/2$.

- 3) Define the number of iteration₁, for finding best (least) Error function.
- 4) Define weighting factor $F(\omega)$ and desired magnitude response of filter $D(\omega)$ using eqs. 11 and 12.
- 5) Calculate Fitness function (Error function) using eq.(15).
- 6) Define number of iteration₂, for finding best particle $X(k)$ very fast.
- 7) Find the center of mass according of each column of $X(k)$ to eq.(7). Best fitness individual can be chosen as the center of mass.
- 8) Calculate new candidates around the center of mass by using eq.(8).
- 9) Now increasing the number of iteration₂ by 1 and Return to Step 6 until stopping criteria has been met.
- 10) Now increasing the number of iteration₁ by 1. Repeat the procedure from step 3 until stopping criterion has been met.
- 11) Thus, optimal solution $X(k)$ and Error function $\epsilon(\omega)$ is obtained. The components of the solution $X(k)$ represent the optimum coefficients of the filter, $a(k)$.

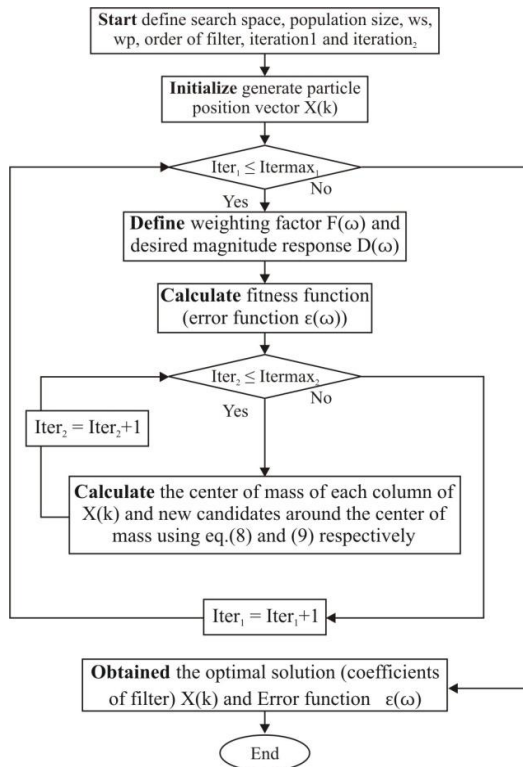


Fig: 3 detail flowchart showing the design of digital filters using BB-BC algorithm.

V. RESULT

The filters are designed to optimize the coefficients which give the best frequency response. This is determined by the ripples on the pass band and the stop band. In this paper, the desired ripple on the pass band ρ_p is 0.016 and that on the stop band ρ_s is 0.040. In this case, pass band and stop band cut off frequencies are 0.9 and 0.12 respectively. Filters with 27 coefficients are designed. For BB-BC, population size of 20 is chosen and 05 iterations ($iter_1$) and 10 iterations ($iter_2$) are used. The value of constants 'P' has been taken as 2. The experiment has been implemented in MATLAB. The coefficients obtained from BB-BC filter design method have been listed in the table 1.

Table:

COEFFICIENTS OBTAINED USING BB-BC OPTIMIZATION METHOD [05 ITERATIONS ($iter_1$)]

Coefficients	BB-BC
1 (15)	0.1460
2 (16)	0.1293
3 (17)	0.1466
4 (18)	0.1227
5 (19)	0.1301
6 (20)	0.1517
7 (21)	0.1248
8 (22)	0.1229
9 (23)	0.1476
10 (24)	0.1384
11 (25)	0.1237
12 (26)	0.1260
13 (27)	0.1329
14	0.2586

The error and magnitude graph are obtained from design have been plotted. Fig 4 and fig 5 shows the error graph and magnitude response of FIR filter respectively, obtained by using BB-BC method. It can be observed that BB-BC converges to much lower fitness in less number of iterations as compare to other methods such as GA, PSO, and DEPSO.

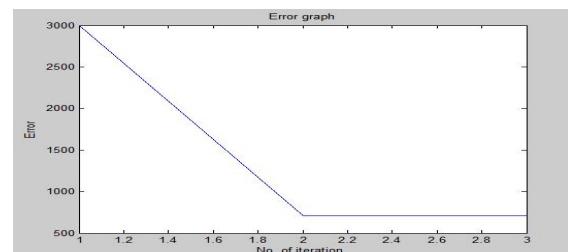


Fig: 4. Error graph of FIR filter obtained by using BB-BC method

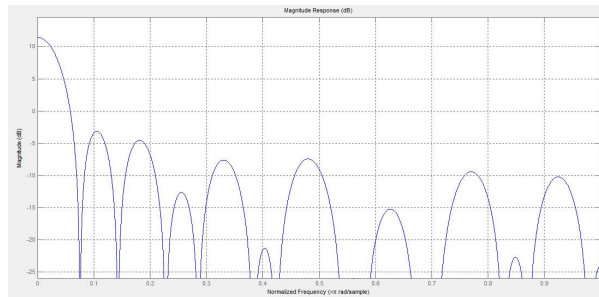


Fig : 5. Magnitude response of FIR filter obtained by using BB-BC method

VI. CONCLUSION

A Big Bang-Big Crunch optimization (BB-BC) is developed for the optimal FIR filter design problems. This method consists of a Big Bang phase where candidate solutions are randomly distributed over the search space, and a Big Crunch phase working as a convergence operator where the center of mass is generated. The comparison of numerical results of optimal FIR filter design problems using the BB-BC method with the results obtained by other heuristic approaches like PSO and GA are performed to demonstrate the robustness of the present algorithm. The BB-BC optimization has several advantages over other evolutionary methods: Most significantly, a numerically simple algorithm and heuristic methods with relatively few control parameters; and the ability to solve problems that depend on large number of variables. Further research is required to evaluate this scenario for digital filter design especially in a dynamic environment.

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