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Optimization of Control Parameters of Differential Evolution Technique for Design of Digital FIR Band-Pass Filter

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Abstract- This paper establishes the technique for the robust design of band-pass Digital FIR Filters by exploring the Five Mutation Strategies of Differential Evolution (DE). Digital FIR Filters are stable and can be guaranteed to have linear phase. The DE algorithm used in this paper to design the Digital FIR Filter is a simple, powerful Evolutionary Algorithm for global numerical optimization problems. DE algorithm has been successfully applied to well-known non-linear and non-differentiable functions. A multi-criterion optimization is employed as the design of band-pass Digital FIR Filter that undertakes the different performance necessities such as minimization of magnitude approximation error, and ripple magnitudes of pass-band and stop-band. This developed DE algorithm also allows the design of other three types of Digital Filters such as low-pass, high-pass, and band-stop filter. The proposed DE algorithm is capable of creating designs of Digital FIR Filters with high accuracy in magnitude response and phase response.

Keywords-Digital Filters, FIR Filters, Optimization, Differential Evolution (DE) Algorithm, Mutation Strategies.

I. INTRODUCTION

The relation of one parameter to another is described by Signal. Categorization of signals can be done in continuous-time signals and discrete-time signals depending on their variations with time, whether these are continuous or at discrete instants of time. Over the last few decades, there is a rapidly increase in technological world. These incredible changes of development in areas of Science and Engineering are due to the powerful technology Digital Signal Processing (DSP). DSP has become more popular due to number of advantages over Analog Signal Processing. These advantages are such as low equipment cost, easy to re-configure and store, better accuracy, flexibility. DSP presents different algorithms, specialized technologies in each field, like Medical Imaging, Communications, RADAR and SONAR, High Fidelity Music reproduction [3,6,16,22].

All functions of filtering such as perfection in signal quality, extraction of significant from signals, to split the signal into desired bands of frequency are performed by filters. Filter extracts meaningful information, provides spectral shaping by reducing the unwanted noise from the input signal. The low pass, high pass, band pass and band stop are the categories of digital filters on the basis of frequency range. Essentially Filters are classified into two categories i.e. Analog Filters and Digital Filters. Analog filters works on continuous-time signals while digital filters perform arithmetic operations on digital signals [20,28,29].

On the basis of impulse response, digital filters can be broadly classified into Non-Recursive i.e. Finite Impulse Response (FIR) and Recursive i.e. Infinite Impulse Response (IIR) filters. The IIR Filters (Recursive) have infinite duration, and depend on previous inputs as well as previous outputs. The FIR (Non-recursive) filter has finite duration impulse response having no feedback. Even, IIR filters can be used for high speed designs, but IIR filters also exhibit some shortcomings such as non-linear phase response, potentially unstable, and the problem occurs in design due to multi-modal error surface. The FIR filters achieve linear phase, simple structure, and remains stable. FIR filters have symmetric and anti-symmetric properties. Design methods of FIR filters are: Optimal filter design, frequency sampling Technique, Window method. Out of these design methods, the Optimization algorithms can be used for design of Digital FIR Filters, because the Optimization algorithm has an ability to give the better performance [6,22,30].

The procedure of making something fully perfect and useful is defined as Optimization. Optimization increases the efficiency of production and reduces cost of production. The Gradient method, Direct Search, and Nature Inspired methods are types of Optimization technique. Gradient based methods uses first or second derivative of objective function to implement the search process in locating the minimum point for continuous and differentiable functions. The drawbacks of Gradient method are that it is not suitable for discontinuous functions and for functions in which derivatives does not exists. In Direct search method, only the objective function values are used to realize the search strategy for locating the minimum point and these methods don't use any derivative of the objective function. So, the direct search method is suitable only for finding the local solution. This method is not applicable to finding the global optimum point. The Evolutionary Algorithms (EAs) or Nature Inspired Methods has become more popular due to number of advantages than Gradient method, Direct search method. The EAs are globally robust and preserve numerous solutions in single simulation run. The EAs are further divided into Genetic Algorithms (GA), Simulated Annealing (SA), Ant colony Optimization (ACO), Artificial Bee Colony (ABC), Particle Swarm Optimization (PSO), Predator Prey

Optimization (PPO) and Differential Evolution (DE). Differential Evolution (DE) differs from other techniques of Optimization and successfully applied to non-linear, non-differentiable, and non-convex functions. DE algorithm is easy yet powerful and uncomplicated features make it very attractive for arithmetical optimization [4,21, 24,25, 29].

Das and Suganthan [14] discussed the most powerful parameter Differential Evolution (DE), gave major variants of DE, and described the applications to multiobjective, constrained, large scale optimization and unconstrained optimization problems. Karaboga [6] defined DE algorithm as a new heuristic optimization approach. By comparing DE with Standard GA, it was observed that performance of DE algorithm is better than Standard GA in terms of computation time and convergence speed. Chandra and Chattopadhyay [23] described a soft computational technique named Differential Evolution algorithm to the design of multiplier-less low-pass FIR Filter and carried out the analysis of Mutation Strategies. It was observed that best/1 Mutation Strategy can be regarded as best approach for design problem.

The aim of this paper is to propose a Differential Evolution Optimization method for designing of band-pass Digital FIR Filter. Filter coefficients values have been optimized using DE algorithm to achieve the magnitude errors, ripple errors as optimal solution of objective function for optimization problem. This paper is organized as following sections: Section II describes the procedure about the FIR Filter Design problem. Section III proposes a DE technique for the design of band-pass FIR Filter and details regarding the DE algorithm. Section IV, the results have been obtained and performance of DE algorithm has been evaluated. In Section V, the conclusion and future scope is described.

II. FIR FILTER DESIGN PROBLEM FORMULATION

In this section, method has been presented for the design of linear-phase Digital FIR Filter under the prescribed conditions given in Table 2.1. A Digital Finite Impulse Response (FIR) Filter is defined as a finite duration of impulse response with no feedback. For Digital FIR Filter, design problem can be stated as (i) the highest tolerable pass-band ripple (ii) the highest tolerable stop-band ripples (iii) the pass-band edge frequencies (iv) the stop-band edge frequencies. The design of Digital FIR Filter is described by the following Eq.2.1 [9,22]:-

$$x(n) = \sum_{k=0}^{M-1} a_k\ y(n-k) \tag{2.1}$$

Where $\{a_k\}$ is the set of coefficients of Filter, $x(n)$ is the output response, $y(n-k)$ is the input sequence, M is the length of Filter. The above Eq.2.1 has been expanded as given below:-

$$x(n) = a_0 y(n) + \cdots + a_{M-1}\, y(n-M+1) \tag{2.2}$$

According to the BIBO stability, if the system produces bounded output for bounded input, then the system is said to be stable system. From above Eq.2.2, it has been observed that filter coefficients of 'a_k'are stable. Therefore, Digital FIR Filters are always stable Filters.The transfer function of FIR Filter has been characterized as [9,22]:-

$$H(z) = \sum_{k=0}^{M-1} a_k z^{-k} \tag{2.3}$$

Digital FIR Filters demonstrate the symmetric and anti-symmetric properties, which are related to their impulse response $h(n)$ as described as follows:-

$$h(n) = h(M-1-n) \qquad \text{For even} \tag{2.4.1}$$

$$h(n) = -h(M-1-n) \qquad \text{For odd} \tag{2.4.2}$$

The number of multiplications is reduced from M to $M/2$ for even, and M to $M-1/2$ for odd. Thus, the following equation should be satisfied by a linear phase Digital FIR Filter [22].

$$h(n) = \pm h(M-1-n) \quad n = 0,1,..M-1 \tag{2.5}$$

Design of Digital FIR Filters is done by optimizing or minimizing the coefficients such as Magnitude Errors, Ripple Magnitudes. The absolute error $e_{m1}(x)$ and squared error $e_{m2}(x)$ are described below in Eq. 2.6, and Eq. 2.7:-

$$e_{m1}(x) = \sum_{i=0}^{k} \left| H_d(\omega_i) - |H(\omega_i, x)| \right| \tag{2.6}$$

$$e_{m2}(x) = \sum_{i=0}^{k} \left(\left| H_d(\omega_i) - |H(\omega_i, x)| \right| \right)^2 \tag{2.7}$$

The desired magnitude response for Digital FIR Filter is described in following equation:-

$$H_d(\omega_i) = \begin{cases} 1 & for \omega_i \in passband \\ 0 & for\ \omega_i \in stopband \end{cases} \tag{2.8}$$

The ripple magnitudes for pass band (δ_p) and stop band (δ_s) have been described as follows

$$\delta_p(x) = max\{|H(\omega_i, x)|\} - min\{|H(\omega_i, x)|\} \qquad for\ \omega_i \in passband \tag{2.9}$$

$$\delta_s(x) = max\{|H(\omega_i, x)|\} \qquad for\ \omega_i stopband \tag{2.10}$$

The multi criterion constrained optimization problem has been stated in Eq. 2.12 by combining all objectives described below.

$$\text{Minimize } f_1(x) = e_{m1}(x) \tag{2.11.1}$$

$$\text{Minimize } f_2(x) = e_{m2}(x) \tag{2.11.2}$$

$$\text{Minimize } f_3(x) = \delta_p(x) \tag{2.11.3}$$

$$\text{Minimize } f_4(x) = \delta_s(x) \tag{2.11.4}$$

A single optimal point can be found in multiple-criterion constrained optimization by solving the following equation [26]:-

$$\text{Minimize } f(x) = \sum_{k=0}^{4} \omega_k f_k(x) \tag{2.12}$$

The prescribed design conditions for band-pass Digital FIR Filter has been given in Table I. below[24]:-

Table I: Design Conditions for Digital FIR Band-Pass Filter

Filter Type	Pass-Band	Stop-Band	Max value of $\{\|H(\omega,x)\|\}$
Band-Pass	$0.4\pi \leq \omega \leq 0.6\pi$	$0 \leq \omega \leq 0.25\pi$ $0.75 \leq \omega \leq \pi$	1

III. DIFFERENTIAL EVOLUTION (DE) ALGORITHM

Differential Evolution (DE) algorithm had been introduced by Storn and Price in 1995 to overcome the drawbacks of Genetic Algorithm in numerical optimization problems with enhanced performance [6]. DE algorithm works on continuous spaces and uses very few parameters [30]. The advantages of DE have been described below [6,24,30]:-

(1) DE is a straightforward and fast approach.
(2) In spite of the primary parameter value, DE has the ability to find the true global minimum.
(3) The nature of DE is parallel processing.
(4) The convergence speed of DE is faster.
(5) DE is capable of providing multiple solutions in single run and in DE, few control parameters are required.

DE algorithm is a population-based algorithm . The DE algorithm apply NP×D dimensional parameter vectors as a population for each generation G

$$x_{i,G,i} = 1,2,\ldots\ldots,NP \tag{3.1}$$

This population NP has been enhanced by applying the operations Mutation, Crossover, and Selection [2,6].

3.1 MUTATION:-

In Mutation there has a generation of new parameter vector by adding the weighted difference between two vectors to a third vector called mutation factor (f_m)

$$v_{i,G+1} = x_{r_1,G}1 + f_m(x_{r2,G} - x_{r3,G}) \tag{3.2}$$

where, $i, r_1, r_2, r_3 \in [1,2,\ldots,NP]$, randomly selected and different from each other. f_m is Mutation Factor belonging to the range [0,2]. $v_{i,G+1}$ is donor vector. Out of ten, the five Mutation Strategies of DE algorithm has been discussed in this paper as follows :-

$$v_{ij}^{t+1} = x_{r1}^t + f_m(x_{r2}^t - x_{r3}^t) \tag{3.3}$$

$$v_{ij}^{t+1} = x_{Bj}^t + f_m(x_{r1j}^t - x_{r2j}^t) \tag{3.4}$$

$$v_{ij}^{t+1} = x_{ij}^t + f_B(x_{Bj}^t - x_{ij}^t) + f_m(x_{r1j}^t - x_{r2j}^t) \tag{3.5}$$

$$v_{ij}^{t+1} = x_{Bj}^t + f_m(x_{r1j}^t + x_{r2j}^t - x_{r3j}^t - x_{r4j}^t) \tag{3.6}$$

$$v_{ij}^{t+1} = x_{r5j}^t + f_m(x_{r1j}^t + x_{r2j}^t - x_{r3j}^t - x_{r4j}^t) \tag{3.7}$$

Where; (i= 1,2,…… NP; j=1,2,…..,D) and t is the generation (time);

$x_i^t = [x_{i1}^t, x_{i2}^t, \ldots., x_{iN}^t]^T$ stands for the position of the ith individual population of real valued NG-dimensional vectors; $v_i^t = [v_{i1}^t, v, \ldots., v_{iN}^t]^T$ stands for the stands for the position of the ith individual of a Mutation Factor(f_m); $r1, r2, r3, r4$ and $r5$ are mutually different integers that are also different from the running index, i, randomly selected with uniform distribution from the set $\{1, 2, i-1, i+1, \ldots.. N\}$, and $f_m > 0$ is a real parameter.

x_{Bj}^t is the best performing vector of the current generation and f_B is applied to control the greediness of the scheme which usually it is set equally to f_m to reduce the number of control variables[5,6].

3.2 CROSSOVER:-

The binomial crossover has been introduced to increase diversity of the perturbed parameter vectors. Parameters of Mutation Factor (f_m) has been mixed with the parameters of another fixed vector, i.e. target vector $x_{i,G,i}$, to produce the trial vector $u_{i,G+1}$

$$u_{ji,G+1} = \begin{cases} v_{ji,G+1} & if(randb(j) \leq CR) or\ j = rnbr(i) \\ x_{ji,G} & if(randb(j) > CR) and j \neq rnbr(i) \end{cases} \tag{3.8}$$

where $randb(j)$ is the j^{th} evaluation of a uniform random number generator with result $\in [0,1]$. $rnbr(i) \in 1,2,\ldots,D$, is a randomly chosen index. $rnbr(i)$ ensures about the selection of at least one parameter vector from $v_{ji,G+1}$ to $u_{ji,G+1}$ [2].

3.3 SELECTION:-

This is the final step for DE operation. In selection process, the performance of trial vector $u_{i,G+1}$ with target vector $x_{i,G,i}$ compared under the greedy selection. This can be described as in following Eq.3.9 :-

$$x_{i,G+1} = \begin{cases} u_{i,G+1} & if\ f\left(u_{i,G+1}\right) < f(x_i, G) \\ x_{i,G} & otherwise \end{cases} \tag{3.9}$$

where $i = 1,2,\ldots N$.

If trial vector yields al lower cost function than target vector, then $x_{i,G+1}$ is same as trial vector, otherwise the old value of target is retained [2,6,23].

3.4 Differential Evolution (DE) Algorithm [5]:-

Steps for Differential Evolution algorithm have been explained below:-

1. Read data i.e. population size (NP), Mutation Factor(f_m), Crossover Rate (CR).
2. Specify the maximum no. of iterations(IT MAX).
3. Generate an array NP×D of uniform random numbers.
4. Assemble calculated objective function in ascending order and select first half of the population members.
5. Set iteration counter; IT=0.
6. Increment iteration counter; IT=IT+1.
7. Select best member from all members on the basis of optimum objective function.
8. Implement Eqn. (3.3) to Eqn. (3.7) to generate the donor vector.
9. Generate trial vector from target vector as described in Eqn.(3.8).
10. Apply Crossover operation to choose one vector from the target and trial vector.
11. Check maximum number of iterations is done or not.
12. If IT<MAX IT, then go to step 6.
13. Note down the GBEST
14. Check the maximum no. of runs (MAX RUN), if not go back to step 2.
15. Stop.

IV. RESULTS

The algorithm has been implemented by varying the filter order and by changing other parameters of DE such as Population size, Mutation Factor (f_m), and Crossover Rate (CR).

Firstly, the order of filter has to be decided and which has been executing the DE algorithm for Mutation Strategy-2 and by varying the Filter Order. Five Mutation Strategies given in Eq.3.3, Eq.3.4, Eq.3.5, Eq.3.6 and Eq.3.7 have been implemented on the selected filter order. Then the parameter such as Population size, Mutation Factor (f_m), and Crossover rate (CR) have been varied on selected Mutation Strategy. The maximum number of iterations has been taken 100 and executed for 100 times to achieve the minimum value of Objective Function. The results have been shown below:-

4.1 SELECTION OF ORDER:-

The DE algorithm has been implemented on Mutation Strategy-2 by varying the Filter Order from 20 order to 36 order**.** Objective function value remains constant from 20 order to 26 order, then it goes to decreasing from 26 order to 28 order. From 28 order to 36, the Objective Function value starts increasing. The behavior of change in achieved values of Objective Function with varying the Filter Order is depicted in Fig.1.

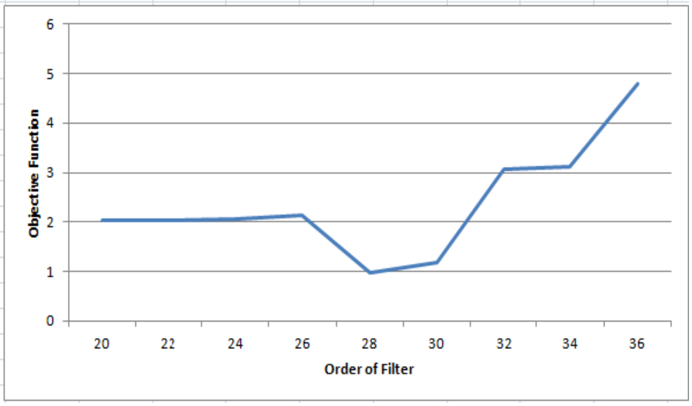

Fig.1: Objective Function value versus. Order of the Filter

From the above Fig.1, it is evident that objective function value is optimum at filter order 28. So the filter order 28 has been selected for the design of band-pass Digital FIR Filter.

4.2 SELECTION OF MUTATION STRATEGY:-

Five Mutation Strategies as explained in Eq. 3.3, Eq.3.4, Eq.3.5, Eq.3.6., and Eq.3.7 applied at selected filter order 28 and the achieved values of Objective Function are shown in Table II:-

Table II: Objective Function of Different Mutation Strategies on **Filter Order 28**

Sr. No	Mutation Strategies	Objective Function
1	Mutation Strategy 1	0.990403
2	Mutation Strategy 2	0.975186
3	Mutation Strategy 3	0.964889
4	Mutation Strategy 4	0.862708
5	Mutation Strategy 5	0.942940

4.3 SELECTION OF POPULATION SIZE:-

From above Table II, optimum Objective Function is achieved at Mutation Strategy-4.For **Mutation Strategy-4,** the population size has been varied from 60 to 200 in steps of 20 to obtain minimum objective function. The corresponding values of Objective Function achieved have been depicted in Table III below.

Table III: Population Size versus Objective Function

Sr. No.	Population Size	Objective Function
1	60	0.951890
2	80	0.928439
3	100	0.862708
4	120	0.799810
5	140	0.796584
6	160	0.772889
7	180	0.799365
8	200	0.794737

From the above values of Population and Objective Function, The graph has been plotted between Population and Objective function has been shown in Fig.2 below:-

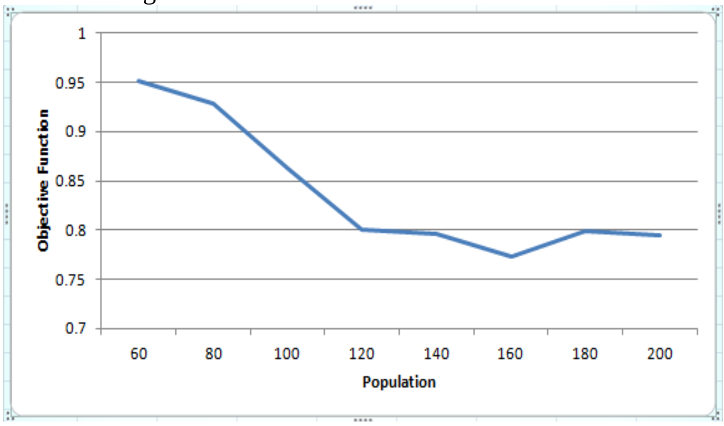

Fig.2: Population vs. Objective Function

4.4 SELECTION OF MUTATION FACTOR (f_m):-

From the above Fig.2, it is evident that DE algorithm for Mutation Strategy-4 with **Population 160** gives the optimum results. Keeping 160 as Population value, the Mutation factor (f_m) has been varied from 0.4 to 1.0 in steps of 0.2. The achieved values of Objective Function by varying the Mutation Factor (f_m) have been depicted in IV below.

Table IV: Mutation Factor versus. Objective Function

Sr. No.	Mutation Factor(f_m)	Objective Function
1	0.4	0.939319
2	0.6	0.939319
3	0.8	0.772889
4	1.0	2.776467

The graph of different values of Objective Function at different values of Mutation Factor has been shown in Fig.3 below:-

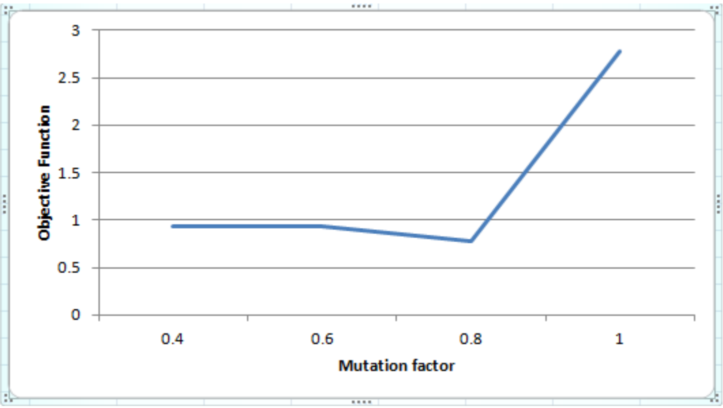

Fig.3: Mutation Factor (f_m) vs. Objective Function

From the graph shown in Fig 5.3, it is clearly observed that DE algorithm at Mutation factor 0.4 to 0.6, the Objective Function remains constant; from 0.6 to 0.8, the Objective Function starts decreasing. From Mutation Factor (f_m) 0.8, the value of Objective Function starts increasing. At Mutation Factor 0.8, the Objective Function value is optimum.

4.5 SELECTION OF CROSSOVER RATE (CR):-

Now, by keeping the value of Mutation factor (f_m) as 0.8, the values of Crossover Rate (CR) have been changed from 0.1 to 0.4 in steps of 0.1.

By keeping the value of **Mutation factor (f_m)** as **0.8**, the values of Crossover Rate (CR) have been changed as shown below:-

Table V: Crossover Rate versus. Objective Function

Sr. No.	Crossover Rate	Objective Function
1	0.1	0.816864
2	0.2	0.772889
3	0.3	0.806872
4	0.4	0.748991

From the above values of Objective Function, The graph of Crossover rate versus. Objective Function has been plotted below:-

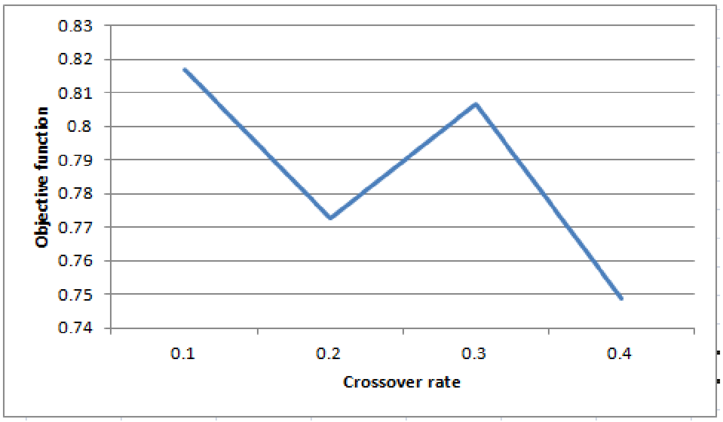

Fig.4: Crossover Rate versus. Objective Function

From the above graph, it has been observed that DE algorithm at Crossover rate (CR) 0.1 to 0.2, the Objective Function value decreases and then it starts increasing rapidly from 0.2 to 0.3. So, at the Crossover Rate 0.4, the Objective Function value is optimum. The minimum Objective Function is achieved at Crossover Rate 0.4.

Design results for band-pass filter has been described in following Table VI.

Table VI: Design Results for Band-Pass Filter

S. No	Magnitude Error 1	Magnitude Error 2	Pass-Band Performance	Stop-Band Performance
1	0.479678	0.052198	0.992248≤|H(ω)|≤ 1.002222 (0.009973)	|H(ω)|≤0.011692 (0.011692)

*The Magnitude Response (in decibels):-*The band of frequencies that passes or the pass-band is defined to be pass-band, where $0.4\pi \leq \omega \leq 0.6\,\pi$ are cut-off (3 dB) frequencies. The Magnitude with respect to normal frequency of band-pass Digital FIR Filter has been plotted below.

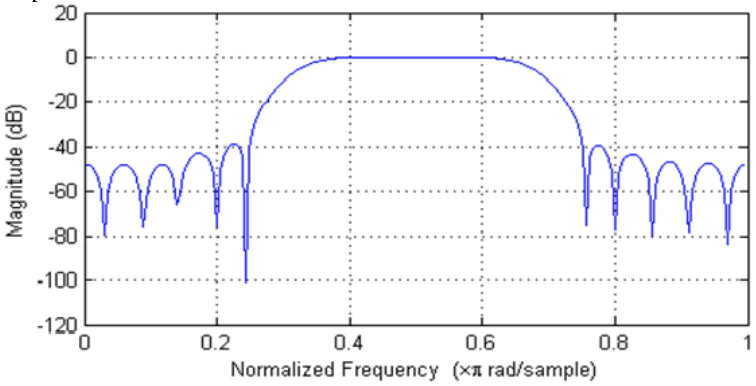

Fig.5: Magnitude response (in dB) for band–pass Digital FIR Filter with Filter Order 28 and Mutation Strategy-4

Magnitude Response:-

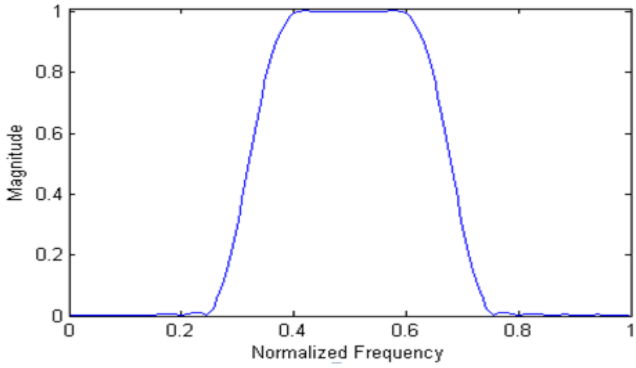

Fig.7: Magnitude Response for band-pass Digital FIR Filter with Filter Order 28 and Mutation Strategy-4

Phase Response:- Linear phase is a property of FIR Filters. From Fig .6, it has been observed that phase of band-pass FIR Filter is linear from 0.25π to$0.75\,\pi$.

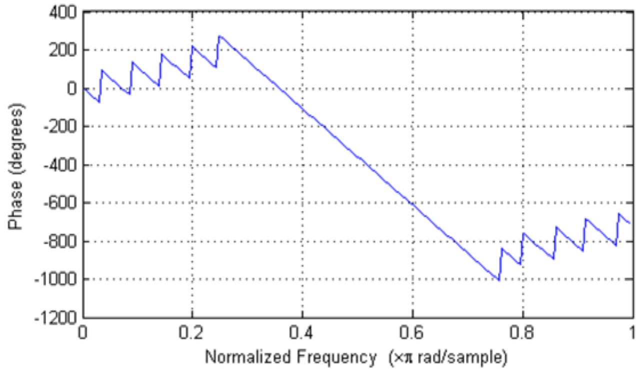

Fig.6: Phase response for band –pass Digital FIR Filter with Filter Order 28 and Mutation Strategy-4

The Magnitude Response of band-pass filter has been depicted in above Fig.7 which shows the stability of designed band-pass Digital FIR Filter.

TABLE VII: Achieved Objective Function for Filter Order 28 with Mutation Strategy-4

S.No	Minimum Objective Function	Maximum Objective Function	Average Objective Function	Standard Deviation
1	0.748991	1.290542	0.987936	0.094208

The results obtained in Table VII, depicts that Standard Deviation (SD) is 0.094208 which is less than 1. So it has been concluded that DE algorithm for the design of band-pass Digital FIR Filter is robust in nature.

V. CONCLUSION

Differential Evolution is a simple and straightforward technique having great accuracy and fast convergence speed. The chosen values of Population, Mutation Factor (f_m) and Crossover rate (CR) are 160, 0.8, 0.4 respectively. The maximum number of iterations has been taken 100 and executed for 100 times to achieve the minimum value of Objective Function. By combining the results it is concluded that DE algorithm with Filter Order 28, Mutation Strategy-4, Population size 160, Mutation Factor (f_m) 0.8, and Crossover Rate 0.4 gives the optimum results for designing a band-pass Digital FIR filter.

The optimum result has a band-pass Digital FIR Filter has been designed by implementing DE algorithm on five different Mutation Strategies. The Filter Order 28 is selected by executing the DE algorithm for Mutation Strategy-2 and by varying the Filter Order 20 to 36. Then, Five Mutation Strategies have been applied on selected Filter Order and Strategy-4 gave the best performance. For Mutation Strategy-4, the parameters of DE algorithm such as Population, Mutation Factor(f_m), and Crossover Rate (CR) have been varied. Best value of Objective Function is selected at Filter Order 28, Mutation Strategy-4, Population Size 160, Mutation factor (f_m) 0.8, Crossover Rate (CR) 0.4. The obtained Minimum, Maximum, Average values of Objective function and Standard Deviation for the design of band-pass Digital FIR Filter with DE algorithm are 0.748991, 1.290542, 0.987936, 0.094208 respectively.

On the basis of above results, it can be concluded that DE algorithm approach for the design of Digital FIR Filters is very much feasible and robust in nature and it allows each FIR Filter design, whether it is low-pass, high-pass, band-pass, or band-stop filter.

REFERENCES

[1] S.S.Rao, "*Optimization theory and Applications"*, (Wiley Eastern Limited, Second Edition, New Delhi, 1990).

[2] Rainer Storn and Kenneth Storn,*"Diiferential Evolution- A Simple and Efficient Heurisitic for Global Optimization over Continuous spaces",* Journal of Global Optimization, vol.11, no.4, pp.341-359, 1997.

[3] Steven W. Smith, "*The Scientist and Engineer's Guide to Digital Signal Processing",* (California Technical Publishing, Second Edition, 1997-99).

[4] K.Deb, *"Optimization for Engineering Design: Algorithms and Examples",*(PHI Learning Pvt. Ltd, First Edition, New Delhi, Feb 2004).

[5] D.P. Kothari, J.S. Dhillon, "*Power System Optimization*", (PHI Learning Pvt. Ltd, Second Edition, 2004).

[6] Nurhan Karaboga,*"Digital IIR Filter Design Using Differential Evolution Algorithm",* EURASIP Journal on Applied Signal Processing, pp. 1269-1276, 2005.

[7] Jinn-Tsong Tsai and Jyh- Horng Chou, *"Design of Digital IIR filters by using an Improved Immune Algorithm",* IEEE Transactions on Signal processing, vol. 54, no. 12, pp.4582-4596, December 2006.

[8] Yang Yu and Yu Xinjie, *" Cooperative Coevolutionary Genetic Algorithm for Digital IIR Filter Design"*, IEEE Transactions on Industrial Electronics, vol.54, no. 3, pp.1311-1318,June 2007.

[9] John G. Proakis, Dimitris G. Manolaiks, "*Digital Signal Processing: Principles, Algorithms, Applications",*(Pearson Prentice Hall, Fourth Edition, United States,2007).

[10] Md. Sakhawat Hossen, Fazle Rabbi, and Md. Mainur Rahman, "*Adaptive Particle Swarm Optimization (APSO) for Multimodal Function Optimization"*, International Journal of Engineering and Technology, vol. 1, no.3, pp. 98-103, 2009.

[11] S.M. Shamsul Alam , Md. Tariq Hasan, *"Performance Analysis of FIR Filter Design by Using Optimal, Blackman Window and Frequency Sampling Methods",* International Journal of Electrical & Computer Sciences,vol.10, no.1, pp.9-14, February 2010.

[12] Qingshan Zhao & Guoyan Meng, *"Design of Digital FIR filters using Differential Evolution Algorithm Based on Reserved Gene"*, International conference of information science & management engineering, vol. 7, no. 10, pp. 177-180, 2010.

[13] Sophocles J. Orfanidis , "Introduction to Signal processing", (Pearson Prentice Hall, 2010).

[14] S.Das and P.N. Suganthan, *"Differential Evolution-A survey of the State-of-the-Art",* IEEE Transactions on Evolutionary Computation, vol.15, no.1, pp.4-31, Feb 2011.

[15] Ashok Ambardar, "*Digital Signal Processing: A Modern Introduction",* (CENGAGE Learning, Eighth Edition, 2011).

[16] Nurhan Karaboga and Mehmat Bahadir Cetinkaya, *"A Novel and Efficient Algorithm for Adaptive filtering: Artificial bee colony algorithm",* Turk J. Elec. Eng & Computer Sci, vol. 19, no. 1, pp.175-188, 2011.

[17] Wenyin Gong, Zhihua Cai, Charles X.King, Hui Li, *"Enhanced Differential Evolution with Adaptive Strategies for Numerical Optimization",* IEEE Transactions on Systems, MAN, and Cybernetics, vol.41, no. 2, pp.397-413, 2011.

[18] Ranjit Kaur, Manjeet Singh Patterh, and J.S.Dhillon, *"Design of Optimal* L_1 *Stable IIR Digital Filter using Hybrid Optimization Algorithm",* International Journal of Computer Applications, vol. 38, no.2, pp.27-32, January-2012.

[19] Sk.Minhazul Islam, S.Das, Saurabh Ghosh, S.Roy, and P.N. Suganthan, *"An Adaptive differential Evolution Algorithm with Novel Mutation & Crossover Strategies for Global Numerical optimization"*, IEEE Transactions on systems, MAN and Cybernetics, vol.42, no. 2, pp- 482-500, April 2012.

[20] Sonika Gupta, Aman Panghal, *"Performance Analysis of FIR Filter Design by Using Rectangular, Hanning and Hamming Windows Methods"*, International Journal of Advanced Research in Computer Science and Software Engineering, vol. 2, no.6, pp.273-277,June 2012.

[21] W.Zhu, Jian-an Fang, Yang Tang, W. Zhang, Wei Du, "*Digital IIR Filters Design Using Differential Evolution Algorithm with a Controllable Probabilistic Population Size",* Plos. One, vol.7, no.7, pp.1-8, July-2012.

[22] Pardeep Kaur, Simarpreet Kaur, *"Optimization of FIR Filters Design using Genetic Algorithm",* International Journal of Emerging Trends and Technology in Computer Science, vol.1, no.3, pp. 228-232, September – October 2012.

[23] Abhijeet Chandra and Sudipta Chattopadhyay , *"Role of Mutation Strategies of Differential Evolution Algorithm in Designing Hardware Efficient Multiplier-less Low-Pass FIR Filter",* Journal of Multimedia, vol.7, no. 5, pp.353-363, October 2012.

[24] Balraj Singh, J.S.Dhillon, Y.S.Brar, *"A Hybrid Differential Evolution Method for the Design of IIR Digital Filter",* ACEEE Int. Journal on Signal & Image Processing, vol.4, no. 1, pp. 1-10, January-2013.

[25] Balraj Singh, J.S.Dhillon, Y.S.Brar, *"Predator-Prey Optimization Method for the Design of IIR Filter"*, WSEAS Transactions on Signal Processing, vol. 9, no.2, pp.51-62, April-2013.

[26] Ranjit Kaur, Manjeet Singh Patterh, and J.S.Dhillon,, "*Digital IIR Filter Design using Real Coded Genetic Algorithm",* I.J. Information Technology and Computer Science, vol.7, pp.27-35, June-2013.

[27] Nirav Raghajibhai Patel, *"Design & Performance Comparison of Low-Pass Filter Using Kaiser Window & Remez Exchange Algorithm",* International Journal of Emerging Trends in Electrical and Electronics (IJETEE), vol.5, no. 1, July-2013.

[28] Ishu Kamra, Darshan Singh Sidhu, Balraj Singh Sidhu, *"Particle Swarm Optimization Method for the Design of IIR High-Pass Filter",* International Journal of Research in Electronics and Computer Engineering (IJRECE), vol. 2, no.3, pp. 68-72, Jul-Sep 2014.

[29] Amandeep Kaur Maan, Balraj Singh, Darshan S.Sidhu, *"Design of High Order Digital IIR Filter using Heuristic Optimization Technique",* International Journal of Advanced Research in Computer Science and Software Engineering(IIJARCSSE), vol.4, no.10, pp.1-7, October 2014.

[30] Amrik Singh and Narwant Singh Grewal, *"Review on FIR Filter Designing by Implementations of Different Optimization Algorithms"*, International Journal of Advanced Information Science and Technology (IJASIT), vol. 31, no. 31, pp. 171-175, November 2014.

