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Literature Review on FIR Filter Optimization

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Abstract – **In digital communication system, digital information can be sent on a carrier through changes in its fundamental characteristics such as phase, frequency and amplitude. The use of a filter plays an important part in a communication channel because it is effective at eliminating spectral leakage, reducing channel width, and eliminating interference from adjacent symbols (Inter Symbol Interference) ISI.**
In order to reduce the effect of Inter Symbol Interference (ISI) in a digital communication system, different types of transmitting pulse shaping filters have been extensively used in practice. We need to design these filters with some constraints imposed by requirements of the communication system in which we are going to use them. The use of optimization techniques have been proved to be quite useful towards the design of those digital filters with certain specifications. This paper reviews about the uses of optimization systems in digital filter design.

I. INTRODUCTION

A filter is a frequency selective circuit that allows a certain frequency to pass while attenuating the others. 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.

Types of filters

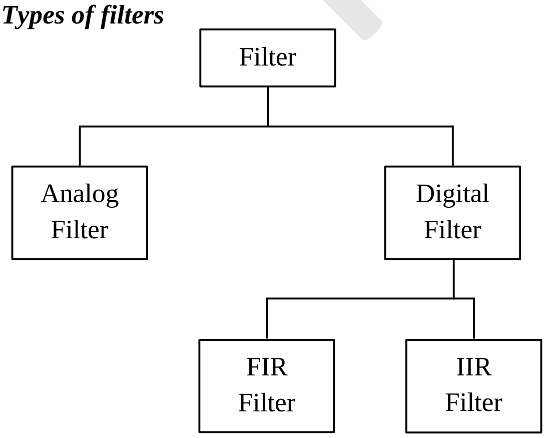

Figure 1: Classification of filters

Figure 1 shows basic classification of filters. Figure 2 shows classification of filters on the basis of frequency.

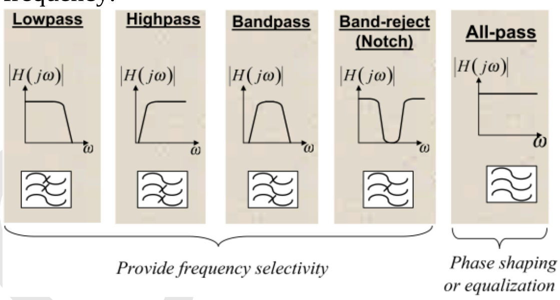

Figure 2: Filter classification on frequency basis

Digital filters are used in wide variety of applications from signal processing, aerospace, control systems, defence equipments, telecommunications, system for audio and video processing to systems for medical applications to name just a few. Basically filter refers to a frequency selective device which extracts the useful portion of input signal lying within its operating frequency range and could be contaminated with random noise due to unavoidable circumstances. Analog filters are implemented with discrete components but the digital filters perform mathematical operations on a sampled, discrete time signal to reduce or enhance the desired features of the applied signal [1].
Digital filers are superior to their analog counterpart due to its wide range of applications and better performance. The advantages of digital filters over analog filters are small physical size, high accuracy and reliability. Digital filtering is one of the most powerful tools of Digital Signal Processing. Digital filters are capable of performance specifications such as ability to achieve multi-rate operation and exact linear phase that would, at best, be extremely difficult, if not impossible, to achieve with an analog implementation. In addition, digital filter characteristics are easy to change under software control. Digital filters are widely used in the fields of automatic control, telecommunications, speech processing and many more. Digital filters are of two

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types; finite impulse response (FIR) and infinite impulse response (IIR) filter which may also take on the names non-recursive and recursive, respectively. Filter designing is a multimodal optimization problem, thus making it a quite interesting and innovative research field. Now a day, FIR filter is designed with the evolutionary techniques, which provides far better control of parameters and more nearly approximate ideal filter. Different heuristics and stochastic optimization methods have been developed which are explained in the following chapter.

II. Literature Review

Genetic Algorithm

Since the beginning of the nineteenth century, a significant evolution in optimization theory has been noticed. Classical linear programming and traditional non-linear optimization techniques such as Lagrange's Multiplier, Bellman's principle and Pontyagrin's principle were prevalent until this century. Unfortunately, these derivative based optimization techniques can no longer be used to determine the optima on rough non-linear surfaces. One solution to this problem has already been put forward by the evolutionary algorithms research community. Genetic algorithm (GA), enunciated by John Holland in the year 1975, is one such popular algorithm which is based on the concept of "survival of the fittest" by Charles Darwin [5]. Holland and his co-workers including Goldberg and Dejong popularized the theory of GA and demonstrated how biological crossovers and mutations of chromosomes can be realized in GA to improve the quality of the solutions over successive iterations.

Genetic algorithm is an optimization method which resembles the natural selection. A set of vectors which can act as a potential solution of the problem at hand is called genome (chromosome). A set of genomes is called population. GA creates new generations by applying some genetic operators to the individuals of population. A typical GA can be summarized as follows:

1. **Initialization**: Generate initial population and compute score of each individual.
2. **Selection**: Select two individuals for mating.
3. **Crossover**: Mate two selected individuals and generate offspring.
4. **Mutation**: Mutate the offspring.
5. **Evaluation**: Calculate scores of offspring.
6. Repeat step 2-5 until a predefined number offspring is generated.
7. **Replacement**: Insert new offspring into the population.
8. Repeat steps 2-7 while termination criterion is not met.

The encoding of the genome and defining an evaluation function or fitness function are the most important parts of GA design process. The structure of the genome must represent a solution to the problem of interest. Evaluation function, on the other hand, compares the performance of genomes to a goal and assigns a score to them. GA uses scores to rank the genomes in population.

Progress of Genetic Algorithm in Digital Filter Design

Genetic Algorithm (GA) based design techniques are widely popular for synthesizing finite impulse response (FIR) filters. An effective design method for minimum phase digital FIR filters using GA has also been described in [6]. While obtaining the optimal-pass band and stop-band responses, the mean squared error (MSE) function is used and to optimize the transition band response the mean absolute error (MAE) is utilized.

Optimizing the design of infinite impulse response (IIR) filter has been achieved using GA, as reported in [6]. The IIR filter design under the mixed criterion of H_2 norm and ∞ norm is proposed in [6] and GA is introduced to realize the filter design based on such criterion. It has been shown that the filter designed by GA is superior to conventional Butterworth filter in terms of either the optimization capability of design method or the performance of designed filter. Using these techniques, the signal to noise ratio (SNR) is improved and the frequency domain performance approaches to theoretical one.

A new method for designing recursive and non-recursive frequency sampling filter has been published in [7]. The use of a hybrid real-coded GA for optimizing transition sample value has been investigated which yields the maximum stop band attenuation. A modification allows the coefficient word length to be optimized concurrently, thereby reducing overall number of design steps and simplifying the design process. The techniques are able to consistently optimize filter with up to six transition samples. The techniques presented in this paper could form the basis for integrating several of the optimizations. Investigation into increasing this integration by using a binary coded GA to optimize nonlinear phase, quantized coefficient FIR filter are introduced, with an analysis of the difficulty of the problem from a GA perspective [7].

For high speed low complexity filter design, it is common practice to constrain the filters‟ coefficient

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to be power of two or a sum of power of two terms (p2), avoiding the full multiplication [7]. Tapped interconnection of different sub filters are sometimes used to enhance ripple and stop band attenuation performances. An extension of the simple cascade architectures, suitable for hardware implementation, is the polynomial sharpening techniques. The design of p2 sharpening filter based on a specific genetic algorithm has been proposed in the above article. The proposed scheme optimizes both the FIR sub-filter and the sharpening polynomial coefficient expressed as p2 terms. This allows getting better performances than the classical p2 design techniques when FIR filters with long impulse response are involved. Using this specific genetic algorithm with a particular free parameters encoding around a set of suitable leading values, allows obtaining a very high reduction of the computational cost. It has been shown in [7] that optimizing both the polynomial and the filter coefficient allow obtaining very good performances; sometimes better that the simple infinite precision sharpening techniques.

Particle Swarm Optimization

The algorithm Particle Swarm Optimization (PSO) was inspired by biological and sociological motivations and can take care of optimality on rough, discontinuous and multimodal surfaces. The aim of this optimization technique is to determine the best-suited solution to a problem under a given set of constraints. Several researchers over the decades have come up with different solutions to linear and nonlinear optimization problems. The optimization problem, now-a-days, is represented as an intelligent search problem, where one or more agents are employed to determine the optima on a search landscape, representing the constrained surface for the optimization problem [8]. In mid 1990s, Eberhart and Kennedy enunciated an alternative solution to the complex non-linear optimization problem by emulating the collective behaviour of bird flocks, particles and called their brainchild Particle Swarm Optimization (PSO) [9].

Kennedy and Eberhart introduced the concept of function-optimization by means of a particle swarm [10]. Suppose the global optimum of an *n*-dimensional function is to be located. The function may be mathematically represented as [11]:

$$f(x_1, x_2, x_3 \dots \dots \dots \dots \dots x_n) = f(\vec{X}) \qquad (1)$$

Where $\vec{X}$ is the search-variable vector, which actually represents the set of independent variables of the given function. The task is to find out such a vector $\vec{X}$ that the function value $f(\vec{X})$ is either a minimum or a maximum denoted by f^* in the search range. If the components of $\vec{X}$ assume real values then the task is to locate a particular point in the n-dimensional hyperspace which is a continuous of such points. At the beginning, a population of particles is initialized with random positions marked by vectors $\vec{X}$ and random velocity. The population of such particles is called a swarm (S). A neighborhood relation N is defined in the swarm. For any two particles P_i and P_j, N determines whether they are neighbors or not. In this case, any particle has all the remaining particles in the swarm in its neighbourhood. It is also equipped with a small memory comprising its previous best position (one yielding the highest value of the fitness function found so far) $p(t)$, i.e., personal best experience and the best $p(t)$ for all $P \in N(P: g(t))$ i.e., the best position found so far in the neighborhood of the particle. When we set $N(P) = S, g(t)$ is referred to as the globally best particle in the entire swarm. The PSO scheme has the following algorithmic parameters:

a. Maximum velocity V_{max} which restricts $V_i(t)$ within the interval $[-V_{max}, V_{max}]$.
b. An inertial weight factor ω.
c. Two uniformly distributed random numbers $\emptyset_1$ and $\emptyset_2$ that respectively determines the influence of $p\ (t)$ and $g(t)$ on the velocity update formula.
d. Two constant multiplier terms C_1 and C_2 known as "self-confidence" and "swarm confidence" respectively.

Progress of Particle Swarm Optimization in digital filter design

Particle swarm optimization techniques can be used to design infinite impulse response (IIR) filter [12]. It is observed that the particle swarm algorithms are able to converge very rapidly when the error surface is relatively constant. This is the fundamental advantage of particle swarm algorithm for online adaptive filtering. Though standard PSO exhibits a fast convergence initially, it fails to improve further because swarm quickly becomes stagnant, converging to a suboptimal solution. However, with the same set of algorithm parameters, the Modified Particle Swarm Optimization (MPSO) particles do not stagnate, allowing it to reach the noise floor along with the GA. Particle Swarm Optimization techniques has also been used to design frequency sampling FIR digital filter [13]. By applying PSO to optimize transition sample values, the maximum stop band attenuation in FIR filter is obtained. It has

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been experimented that to design FIR filter, PSO is more superior to GA not only in the convergence speed but also in the performance of filter [13].

Stable IIR digital filters with non-standard amplitude characteristics can be designed using particle swarm optimization techniques [14]. PSO has been the newly elaborated techniques for optimization of multi-modal functions. Design of IIR digital filters with non-standard amplitude characteristics which considerably differ from typical Butterworth, Chebyshev, and Cauer approximations, is possible using presented method. The IIR digital filter with linearly falling amplitude characteristics is designed with the use of proposed method. The filter is stable and fulfils all prescribed design assumptions.

Based on the study of cultural algorithms and particle swarm optimization, a new method of FIR digital filters design, called Cultural Particle Swarm Optimization (CPSO) has been developed [15]. CPSO is a global convergent algorithm that can find out the global optima of the problem. The algorithm concept and implementation of CPSO are very similar to PSO. The simulation results show that CPSO is better than the original PSO and Quantum-behaved Particle Swarm Optimization (QPSO) with more rapid convergence speed and better performance of the designed filter. In Combinatorial Particle Swarm Optimization (CPSO) the initial population is created randomly from the solution space. The goal of the fitness function is to evaluate the status of each individual. In the FIR digital filter based on CPSO, the target is the minimization of the following objection function.

Differential Evolution

Differential Evolution (DE) [11] algorithm has been emerged as a very competitive form of evolutionary computing more than one decade ago. The first written article on DE appeared as a technical report by R. Storn and K. V. Price in 1995.One year later, the success of DE was demonstrated at the First International Contest on Evolutionary Optimization in May 1996, which was held in conjunction with the 1996 IEEE International Conference on Evolutionary Computation (CEC). DE finished third at the 1st ICEO, which was held in Nagoya, Japan. In quick times, DE has turned out to be the best evolutionary optimization algorithm for solving real valued test function. Price presented DE at the second International contest on Evolutionary Optimization in 1997 and it turned out as one of the best among the competing algorithms. In 2005 CEC competition on real parameter optimization, on 10-D problems classical DE secured 2nd rank and a Self-adaptive DE variant called SaDE [16] secured 3rd rank although they performed poorly over 30-D problems. Later depending upon many improved DE variants some optimization techniques has been proposed in the period 2006-2009 such as , improved SaDE, jaDE [17] ,Opposition Based DE (ODE) [18] , DE with global and local neighbourhoods (DEGL) and so on.

The name of the algorithm is Differential Evolution (DE) to signify a special type of differential operator that has been utilized to create new offspring from the parent chromosomes without adopting classical crossover or mutation. By performing an extensive test bed it has been found that this optimization technique converges faster with more certainly than any other global acclaimed optimization techniques. This algorithm can be implemented very easily using very few parameters tuning which makes the algorithm reasonably popular very soon. Unlike traditional evolutionary algorithms (EAs), the DE variants perturb current generation population members with the scaled differences of randomly selected and distinct population members. Therefore no separate probability density function has to be used for generating the offspring.

Progress of Differential Evolution in Digital Filter Design

Design of digital filters with the aid of Differential Evolution algorithm has been studied extensively in the literature. Design of IIR filter using Differential Evolution (DE) algorithm for both magnitude response and group delay has been investigated in [28]. Design of an 18parameter IIR-filter using Differential Evolution has also been done in [19].

Application of the IIR filter in system identification has been widely studied in [29], since many problems encountered in signal processing can be characterized as a system identification problem. In this case, the parameters of the filters are successively adjusted by the DE algorithm until the error between the output of the filter and the unknown system is minimized. By constraining the range of the filter coefficients, the stability is guaranteed.

It has been studied in [20] that to design an acceptable filter, DE requires less iteration than GA for similar type of design. It has also been experimented that the convergence speed of DE is much better than GA too. For the design of higher order filter, as expected, the algorithms require more generations to design an acceptable filter. The performance of DE and GA has also been compared in terms of the computation time. It was seen that DE

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requires about 2–3 seconds although GA needs approximately 50 seconds to design an optimal IIR filter for 50 generations [20]. In terms of the final solution, the performance of DE is comparable to that of GA since the local search ability of DE is better than that of GA.

Different optimization techniques has judiciously been utilized to determine the impulse response coefficient of digital FIR filter. A digital FIR filter has been designed using convex optimization method [30] and the performance of the filter has been compared with that obtained by DE technique in [31]. The convex optimized as well as DE optimized FIR filter has been used as a pulse-shaping filter in a Quadrature Phase Shift Keying (QPSK) [32] modulated system and the resulting system performance has also been compared with that of standard Raised Cosine (RC) filter. Various performance parameters such as Error Vector Magnitude (EVM), Signal to Noise Ratio (SNR) and Waveform Quality Factor have been evaluated in this regard. The performance of the FIR filter under both Convex and DE optimization techniques have been compared in terms of their magnitude and impulse response too. The effect of an important control parameter namely, the Weighting Factor, on the convergence speed of the DE algorithm associated with the efficient design of low-pass FIR filter, subsequently used as a pulse-shaping filter in a QPSK modulated system, has been investigated in [26]. The optimized value of the Weighting Factor for the specific design problem has also been suggested in the paper [27]. Amongst various mutation strategies of Differential Evolution algorithm selection of computationally efficient mutation strategy for the design of low-pass FIR filter has been stated in [33]. In order to find out the most favourable mutation scheme, the computational efficiency of various mutation schemes has also been studied in [33]. A novel self-adaptive Differential Evolution (SADE) [34] algorithm has been proposed for the design of multiplier-less low-pass linear phase FIR filter to improve the computational efficiency of this algorithm as shown in [34]. The performance of DE optimization technique has been evaluated in terms of its convergence behaviour for different mutation schemes in [23]. After analysing the magnitude and impulse responses the most suitable mutation scheme has been suggested for the specific design problem. An attempt has been made for designing of multiplier-free Finite duration Impulse Response (FIR) digital filter using such robust evolutionary optimization technique as described in [35]. The performance evaluation of the designed filter using Differential Evolution with other existing discrete coefficient FIR model has also been carried out in [25]. Design of low-pass FIR pulse-shaping filter using a novel self-adaptive Differential Evolution Technique has been carried out in [16]. The effect of two control parameter namely weighting factor and cross-over probability of DE optimization technique on the design of low pass FIR filter has extensively been studied in [24]. The De optimized filter has been utilized as a pulse-shaping filter in a QPSK modulated system and its performance has further been studied in terms of Bit Error Rate (BER). The Differential Evolution algorithm has been proposed for the minimization of the number of coefficients of standard raised cosine (RC) pulse-shaping of different lengths, without affecting its performance to a great extent as seen in [36]. It has been established for the simulation results that the proposed filter provides a significant reduction in the number of tap coefficients without much degradation in its performance.

A linear phase finite impulse response (FIR) filter has been designed using Differential Evolution Particle Swarm Optimization (DEPSO) technique as mentioned in [37]. Here two different fitness functions have been studied and experimented, each having its own significance. The first study considers a fitness function based on the pass-band and stop-band ripple, while the second study considers fitness function based on the mean squared error between the actual and the ideal filter response. DEPSO [37] seems to be one of the promising tools for FIR filter design especially in a dynamic environment where filter coefficient have to be adapted and fast convergence is of paramount significance. In recent times, it has been observed that the DE algorithm based on reverse gene can also be applied for the design of digital filter [38]. It can produce new chromosomes in every generation by combining reversed gene of special chromosome into a single entity.

III. Conclusion

Carrying out literature review is very significant in any research project as it clearly establishes the need of the work and the background development. It generates related queries regarding improvements in the study already done and allows unsolved problems to emerge and thus clearly define all boundaries regarding the development of the research project. Plenty of literature has been reviewed by us in connection with optimization systems in digital filter design and the significantly related ones have been discussed in this paper.

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REFERENCE

[1] Ricardo A. Losada, "Digital Filters with MATLAB", The MathWorks, Inc., May 2008.

[2] E. Ifeachor and B. Jervis, "Digital Signal Processing: A practical Approach" 2nd eddition, Prentice Hall, 2002.

[3] P. Ramesh Babu, "Digital Signal Processing", 4th Edition, Scitech Publication Pvt. Ltd, 2007.

[4] S.S. Rao, "Engineering Optimization: Theory and Practice", John Wiley & Sons, 4th edition, 2009.

[5] W. Northcutt, "The Darwin Awards 3: survival of the fittest", Plume, 2004.

[6] LiXue, Z. Rongchun and Wang Qing, "Optimizing The Design of IIR Filter Via Genetic Algorithm", In Proceedings of in Proceedings of IEEE Int. Conf. on Neural &Signal Processing, pp. 476-479, December 14-17, 2003.

[7] P Gentili, F. Piazza and A. Uncini, "Improved Power of Two Sharpening Filter Design by Genetic Algorithm", IEEE Transaction on Filter Design, pp. 1375-1378, March 1996.

[8] A. Konar, "Computational Intelligence: Principles, Techniques and Applications", Springer Berlin Heidelberg, New York, 2005.

[9] J. Kennedy and R. Eberhart,"Particle Swarm Optimization", In Proceedings of IEEE International Conference on Neural Networks,pp.1942-1948, 2005.

[10] J. Kennedy, R. Eberhart and Shi Y, "Swarm Intelligence", Los Altos, CA.

[11] S. Das, A. Abraham and A. Konar, "Particle Swarm Optimization and Differential Evolution Algorithms: Technical analysis, Applications and Hybridization Prospects"in Proceedings of Studies in Computational Intelligence (SCI) 116, pp. 1-38, Springer-Verlag Berlin Heidelberg 2008.

[12] Wan-Ping Huang, Li-Fang Zhou, Ji-XinQian, "FIR Filter Design: Frequency Sampling Filters by Particle Swarm Optimization Algorithm", In Proceedingsof the Third International Conference on Machine Learning and Cybernetics, Shanghai, August 26-29, 2004.

[13] M. Najjarzadeh, A. Ayatollahi, "FIR Digital Filters Design: Particle Swarm Optimization Utilizing LMS and Minimax Strategies", 978-1-4244-3555-5/08, IEEE, 2008.

[14] A. Slowik and M. Bialk, "Design and Optimization of IIR Digital Filters with Non Standard Characteristics Using Particle Swarm Optimization algorithm", In Proceedings of ICECS, 2007.

[15] Z. Zhao and H. Gao, "FIR Digital Filters Based on Cultural Particle Swarm Optimization",in Proceedings of 2009 International Workshop on Information Security and Application (IWISA 2009), 2009.

[16] S. Chattopadhyay, S.K. Sanyal and A. Chandra, "Design of Low-pass FIR Pulse-shaping Filter Using a Novel Self-adaptive Differential Evolution Technique", Advanced Science Letters, vol. 4, no. 11/12, pp. 3746-3748, November/December 2011.

[17] V. Krishnaveni, S. Jayaraman, A. Gunasekaran, and K. Ramadoss, "Automatic Removal of Ocular Artifacts using JADE Algorithm and Neural Network", World Academy of Science, Engineering and Technology13, 2006.

[18] S. Rahnamayan, H.R. Tizhoosh and M.M.A. Salma "Opposition-Based Differential Evolution (ODE with variable jumping rate", in Proceedings of 2007 IEEE Symposium on Foundations of Computational Intelligence, pp. 81-88, June 2007.

[19] R. Storn, "Differential Evolution Design of an IIR-Filter", in Proceedings of Evolutionary Computation, pp. 268-273, May 20-22, 1996.

[20] S. Das, P. N. Suganthan, "Differential Evolution: A Survey of the State-of-the-Art", IEEE Transaction on Evolutionary Computation. vol. 15. no.1, February 2011.

[21] M. Molga, C. Smutnicki, "Test function for Optimization needs", 3 kwietnia 2005.

[22] R. Storn, K. Price, "Differential Evolution-A Simple and Heuristic for Global Optimization over Continuous Spaces", International Journal on Global Optimization pp. 341-359, 1997.

[23] S. Chattopadhyay, S.K. Sanyal and A. Chandra, "Comparison of Various Mutation Schemes of Differential Evolution Algorithm for the Design of Low-pass FIR Filter", in Proceedings of Second International Conference on Sustainable Energy and Intelligent System (SEISCON 2011), pp. 809-814, Chennai, Tamil Nadu, India, July 20-22, 2011.

[24] S. Chattopadhyay, S. K. Sanyal and A. Chandra, "Optimization of Control Parameters of Differential Evolution Technique for the Design of FIR Pulse-shaping Filter in QPSK Modulated System", Journal of Communications, vol. 6, no. 7, pp. 558-570, October 2011.

[25] N. Karaboga and B. Cetinkaya ,"Design of Digital Filter using Differential Evolution Algorithm", International Journal on Circuits Systems Signal Processing, vol. 25, no. 5, pp. 649-660, 2006.

[26] S. Chattopadhyay, S.K.Sanyal and A. Chandra, "Design of FIR filter Using Differential Evolution Optimization & to study its Effect as a Pulse Shaping Filter in a QPSK modulated system", IJCSNS International Journal of Computer Science and Network Security,vol.10,no. 1, pp.313-321,January 2010.

[27] S. Chattopadhyay, S.K.Sanyal and A. Chandra, "Optimization of Control Parameter of Differential Evolution Algorithm for Efficient Design of FIR Filter", in Proceedings of 13th International Conference on Computer and Information Technology (ICCIT 2010), Dhaka, Bangladesh, December 23-25, 2010.

[28] R. Storn, "Differential Evolution Design of an IIR-Filter with Requirements for Magnitude and Group Delay", TR-95-026, June 1995.

[29] N. Karaboga, "Digital IIR Filter Design using Differential Evolution Algorithm", EURASIP Journal on Applied Signal Processing 2005:8, pp. 1269-1276, 2005.

[30] T. N. Davidson, "Enriching the art of FIR Filter design via Convex Optimization", in Proceedings of IEEE Signal Processing Magazine, vol. 27, no.3, pp.89-101, May 2010.

[31] S. Chattopadhyay, S.K. Sanyal and A. Chandra, "Design of FIR Pulse-Shaping Filter: Superiority of Differential Evolution Optimization over Convex Optimization", in Proceedings of 5th European Conference on Circuits and Systems for Communication (ECCSC'10), November 23-25, 2010, Belgrade, Serbia.

[32] S. Haykin, "Adaptive Filter Theory", 3rd Edition, Prentice-Hall, 1996.

[33] A. Chandra and S. Chattopadhyay, "Selection of Computationally Efficient Mutation Strategy of Differential Evolution Algorithm for the Design of Multiplier-less Low-pass FIR Filter", in Proceedings of

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 4, Issue 1, August 2015)

14thInternational Conference on Computer and Information Technology (ICCIT 2011), pp. 274-279, Dhaka, Bangladesh, December 22 24, 2011.

[34] A. Chandra and S. Chattopadhyay, “A Novel Self-Adaptive Differential Evolution Algorithm for Efficient Design of Multiplier-less Low-pass FIR Filter”, in Proceedings of Second International Conference on Sustainable Energy and Intelligent System (SEISCON 2011), pp. 733-738, 2011.

[35] A. Chandra and S. Chattopadhyay, “Novel Approach of Designing Multiplier-less Finite Impulse Response Filter using Differential Evolution Algorithm”, International Journal of Intelligent Systems and Applications, vol. 4, no. 4, pp. 54-62, April 2012.

[36] A. Chandra, S. Chattopadhyay and S.K. Sanyal, “An Efficient Algorithm to Minimize the Number of Coefficients of an FIR Pulse-Shaping Filter”, in Proceedings of Annual IEEE India Conference (INDICON 2010), Kolkata, India, December 17-19, 2010.

[37] B. Luitel and G. K. Venayagamoorthy, “Differential Evolution Particle Swarm Optimization for Digital Filter Design”, in proceedings ofIEEE Congress on Evolutionary Computation (CEC 2008), 2008.

[38] Q. Zhao and G. Meng,“Design of Digital Filters Using Differential Evolution Algorithm Based on Reserved Gene”,In Proceedings of International Conference of Information Science and Management Engineering, 2010.