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Design of FIR Filter Using Particle Swarm Optimization Algorithm for Audio Processing

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Abstract

In this paper, an optimal design of linear phase digital finite impulse response (FIR) filter using Modified Particle Swarm Optimization (MPSO) has been presented. In the design process, the filter length, pass band and stop band frequencies, pass band and stop band ripple sizes are specified. Sometimes the gradient based optimization techniques are not effective for designing filter. An evolutionary method is introduced to find the optimal solution of FIR filter design problem. MPSO is a global stochastic searching technique that can find out the global optima of the problem. A simulation results reveals the optimization efficacy of the algorithm for the solution of, highly non-linear, and constrained filter design problems. The designed filter is then applied on the audio application for up sampling of the audio signal. MATLAB toolkit functions are used for implementation of proposed algorithm.

Keywords: Audio Sampling Rate, FIR low pass filter, Magnitude, Particle Swarm Optimization

1. Introduction

Multi-rate processing and sample rate conversion are the digital processing techniques that broadband and wireless design engineers can implement during the system design process. The process of converting the sampling rate of a signal from one rate to another is called sampling rate conversion while changing the information carried by the signal as little as possible. A digital filter is a system that performs operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal. Digital filters can be used to perform many filtering tasks and are replacing the role of analog filters in many applications. Beside the inherent advantages, such as high accuracy and reliability, small physical size and reduced sensitivity to component tolerances or drift, digital implementations allow one to achieve certain characteristics not possible with analog implementations such as exact linear phase and multi-rate operation digital filtering can be applied to very low frequency signals, such as those occurring in biomedical applications. Depending upon the duration of the impulse response, digital filters are classified as Finite-Duration Impulse Response (FIR) and Infinite-Duration Impulse Response (IIR) filters. FIR filters are used in many signal processing applications due to their linear phase characteristics and stability. The design of FIR digital filter can be taken as any optimization problem that can be discussed in next section. The main problem in the design of non recursive digital filters is to meet the specified magnitude and delay characteristics.

Different techniques have been used for the design of FIR filter, which includes window-based method, frequency sampling method and Parks-McClellan equiripple algorithm. Of late various evolutionary algorithms are also been used for this purpose. Design of linear phase digital low pass FIR filter of different orders using Particle Swarm Optimization with Constriction Factor and Inertia Weight Approach (PSO-CFIWA) is explained in [1].The new method on the design of FIR digital filters based on chaotic mutation particle swarm optimization (CPSO) based on local searching, which improves the performance of the standard PSO is proposed in [2]. Then, the new algorithm was employed to find the optimal solution of FIR coefficients. CPSO has the advantages of more stability, higher optimizing precision and strong global searching capability which makes it an efficient and alternative approach for FIR filters design. The technique of quantum-behaved particle swarm optimization (QPSO) to design FIR digital filters in [3] is a global stochastic searching technique that can find out the global optima of the problem more rapidly than other evolutionary techniques. A new strategy is proposed based on the study of particle swarm optimization of multi-criterion satisfactory optimization Particle swarm optimization [4]. MOAPSO is not only to avoid the particles getting into local best solution during the optimization, but also give attention to the incompatible criterions under the condition of valid solution or minor valid solution. Optimizing transition sample values, to improve the performance of FIR digital filter this technique is applied. A novel recursive scheme in [5] to compute the global and robust optimal variable fractional delay filters based on the Particle Swarm Optimization. If the PSO is directly used to compute an optimal VFD filter the particles with high dimension might be yielded, which could require a long convergence time. This scheme invokes only the particles with much smaller dimension at each step of the computation. Designing of low pass and band pass FIR filters using particle swarm optimization [6] and examines the utility of various error norms such as least mean squares (LMS) and minimax, and their impact on convergence behavior and optimal resultant frequency response. Particle swarm optimization and Differential evolution particle swarm optimization have been used for the design of linear phase finite impulse response (FIR) filters [7] in which he considers different fitness functions based on the passband and stopband ripple, function based on the mean squared error between the actual and the ideal filter response. An optimization design method of FIR digital filter based on frequency sampling technique with Particle Swarm Optimization [8] in which the sample values in transition band are optimized variable and the rate that minimum stopband attenuation to maximum passband ripples. This shows better results in the convergence speed and in the performance of filter. In this paper we have studied the impact of control parameters such as weighting factor with the modified PSO on the convergence behavior of the algorithm for efficient design of low-pass FIR filters. The effect of performance of FIR filters has been evaluated in audio sampling rate conversion application.

This paper is organized as follows: Section II gives the introduction of the Particle Swarm Optimization Algorithm, the FIR low pass filter problem formulation and the brief introduction of the methodology involved in the work. Section III shows the simulation results and performance of the proposed techniques on the audio application and at last section IV concludes the paper and followed by the references.

2. Theoretical Background

2.1. Particle Swarm Optimization

A new algorithm for global optimization has been introduced by Eberhart and Kennedy in 1995. PSO is a search technique based on social behavior of bird flocking and fish schooling. It is a kind of swarm intelligence that is based on social-psychological principles and provides insights into social behavior, as well as contributing to engineering applications. People solve problems by talking with other people about them, and as they interacts their beliefs, attitudes, and behavior changes, the changes could typically be depicted as the individuals moving toward one another in a socio-cognitive space. The particle swarm simulates a kind of social optimization. There are different kinds of bio and social behavior inspired algorithms. PSO is one of the different swarm based algorithms. In PSO, each particle of the swarm is a possible solution in the multi-dimensional search space. A problem is given, and some way to evaluate a proposed solution to it exists in the form of a fitness function. The particles iteratively evaluate the fitness of the candidate solutions and remember the location where they had their best fitness value.

Particle Swarm optimization is similar to Genetic algorithm in that the system is initialized with the population of random solutions. In PSO each potential solution is assigned a randomized velocity , and the potential solutions, called particles, are then flown through multi-dimensional space. Each particle keeps track of its co-ordinates in hyperspace which are associated with the best solution it has achieved. This value is called the pbest i.e local best. Another best value is also tracked. The global version of particle swarm optimizer keeps track of the overall best value and its location, obtained thus far by any other particle in the population called the gbest.

PSO is very simple and efficient algorithm for optimizing a wide range of functions. Conceptually it seems to lie in between Genetic algorithms and Evolutionary algorithms. The adjustment toward pbest and gbest by Particle swarm optimizer is similar to crossover operation utilized by Genetic Algorithm. The main PSO concept is that the flying potential solutions are accerlating towards the better solutions as the other evolutionary computation algorithms operate directly on potential solutions which are represented as locations in hyperspace. Being easy to implement and yet so effective, PSO has been utilized in a wide variety of optimization applications. In this thesis, PSO has been used in audio application and to design digital filters.

A swarm consists of a set of particles, where each particle represents a potential solution. These particles are randomly distributed over the search space with initial position and velocity.

$$X_i = x_{i1}x_{i2}..............x_{iD} \quad (1)$$

$$V_i = v_{i1}v_{i2}...............v_{iD} \quad (2)$$

They change their positions and velocity according to equations where c_1 and c_2 are cognitive and social acceleration constants, $rand_1()$ and $rand_2()$ are two random functions uniformly distributed in the range of [0,1] and w is the inertia weight introduced to accelerate the convergence speed of the PSO.

$$V_{iD}(k+1) = w * V_{iD}(k) + c_1 * rand_1() * (P_{iD} - X_{iD}) + c_2 * rand_2() * (P_g - X_{iD}) \quad (3)$$

$$X_{iD}(k+1) = X_{iD}(k) + V_{iD}(k+1) \quad (4)$$

2.2 Problem Formulation

The transfer function of FIR filter

$$H(z) = \sum_{n=0}^{N-1} h[n]z^{-n}, n = 0,1,.....N \quad (5)$$

where N is the order of the filter which has (N+1) number of coefficients h(n) is the filter impulse response. The values of h(n) determines the type of filter i.e. high pass, low pass, band pass. The parameters for the optimal filter design that are considered are stopband and passband normalized frequencies the passband and stopband ripple the stopband attenuation and the transition width. These parameters are mainly decided by the filter coefficients. In any filter design problem, some of these parameters are fixed while others need to be determined. The evolutionary approaches are applied in order to obtain the actual filter response as close as possible to the ideal response. The fitness function is the error function that is to be optimized. An error function given by is the approximate error used in Parks-McClellan algorithm for filter design:

$$E(w) = G(w)[H_d(e^{jw}) - H(e^{jw})] \quad (6)$$

Where G(w) is the weighting function used to provide different weights for the approximate errors in different frequency bands, $H_d(e^{jw})$ is the frequency response of the desired filter and $H(e^{jw})$ is the frequency response of the approximate filter. The error function is defined as the mean squared error between the frequency response of the ideal and the actual filter. So the error for this fitness function is the squared difference between the magnitudes of this filter. This is called the mean squared error and is given by

$$F = \frac{1}{N}\sum_{K-1}^{N}(ideal(k) - actual(k))^2 \quad (7)$$

Where ideal(K) and actual(K) are the magnitude response of the ideal and the actual filter, and N is the number of samples used to calculate the error.

2.3 Algorithm Description

The basic procedure for implementing the PSO algorithm is as follows:

1. Initialize the swarm by assigning a random position in the problem search space to each particle.
2. Evaluate the fitness function for each particle and find out the pbest.
3. For each individual particle, compare the particle fitness value with its pbest. If the current value us better than the pbest value, then set this value as the current particle position.
4. Identify the particle that has the best fitness value. The value is its fitness function is identified as gbest and its position as Pg.
5. Update the velocities and position of all the particles using "(3)"and "(4)"
6. Repeat steps 2-5 until the stopping criterion is met i.e. sufficient good fitness value.

2.4 Solution Methodology

Various steps used for the designing of FIR Filters are as:

1. Check the response (Frequency response and Magnitude) with the Frequency difference equation of the Fir low pass filter.
2. Get the Coefficients (b, a) and assign it to a matrix that will be optimized. In case, we have only one co-efficient, the other coefficient remain as 1. Secondly Optimization problem optimizes the

magnitude using Particle Swarm Optimization Algorithm by generating the objective function.

3. Design Objective Function based on absolute value difference of frequency response between optimized coefficient and desired coefficient.
4. Fix the tolerance limits for objective and non linear constraint function to promote fast converge.
5. Discretize and eliminate values that that are not free to vary.
6. Check nearest integer values for better filter to be realized.
7. Plot the frequency response after optimization.
8. The designed filter is then applied on the audio sampling rate conversion application for up sampling the signal.

3. Simulation Results

The MATLAB simulation has been performed extensively to realize the low pass FIR filter with the order of 20.Hence the length of the filter coefficients is 21. Also, for the simulations the sampling number was taken as 128. In Table 1 the data taken for the design of low pass filter of order 20 is given. Mathematically, by substituting the values of Pass band, transition width, pass band ripple, stop band attenuation, sampling frequency in any of the methods such as window method, frequency sampling method or optimal method we can get the values of filter coefficients *h(n)*. In this paper, PSO algorithm has been designed which is used to design the low pass FIR in the specified range of parameters and compared with parameters of GA. The filters designed by the PSO algorithm have sharper transition band responses than that produced by GA algorithm. Table 2 shows the Particle Swarm Optimization parameters that are used to optimize the magnitude for FIR Filter. The best optimized coefficients obtained for the designed filter with the order of 20 have been calculated by the two methods and given in Table 3. Fig 1 shows the optimized magnitude response better than other techniques.

Table 1: Filter design Specifications

Filter Specification	Value
Passband Frequency	0,0.5 π
Stopband Frequency	0.6 π ,1
Number of Iterations	4
Cut off frequencies	(0,1)
Order of the filter	20

Table 2: PSO Parameters Specification

Create function type	Constraint type
Evaluation of the fitness function	*h2-h*
Population size	40
Population type Vector	vector
Known minimum	[0 ,0]
Constraint Boundary	Soft
Population Integer range	[0 , 1]
Non linear tolerance	1e-4
Objective function tolerance	1e-6

Table 3: Optimized Coefficients of FIR Filter of Order 20

h(n)	GA	MPSO
h(1) = h(21)	0.0174	0.4492
h(2) = h(20)	0.0085	0.0781
h(3) = h(19)	-0.0164	-0.5340
h(4) = h(18)	0.0157	-0.2913
h(5) = h(17)	0.0248	0.6056
h(6) = h(16)	0.0101	0.6352
h(7) = h(15)	-0.0533	-0.6600
h(8) = h(14)	-0.0632	-1.3340
h(9) = h(13)	0.0703	0.6940
h(10) = h(12)	0.2751	4.4364
h(11)	0.3982	6.3500

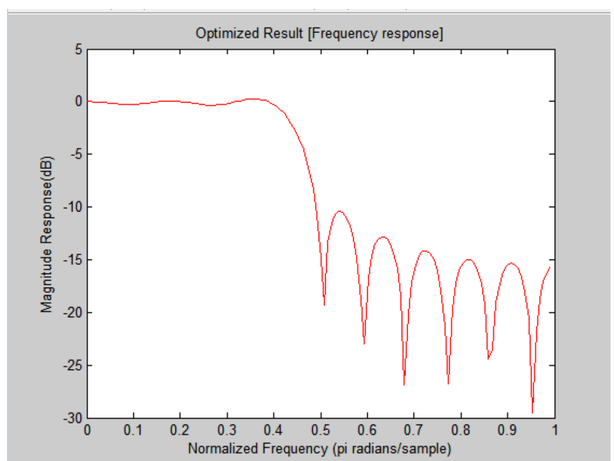

Fig 1: Magnitude plot of FIR low pass Filter of order 20 using PSO

The incoming audio data passes through an upsampler or an interpolation stage. The signal then passes through an designed anti-aliasing low-pass filter followed by a downsampler or decimation stage. The input is upsampled by some factor followed by a Finite Impulse Response (FIR) filter to smooth the signal. This is a simplified form of the polyphase filtering technique, which improves the speed of the SRC. Polyphase filtering can be also be employed to reduce redundancy. Fig 2 shows the original audio signal which is downsampled due to some random noise and needs a filtering operation which is done to upsample the signal with the designed filter and the output upsampled signal is shown in Fig 3.

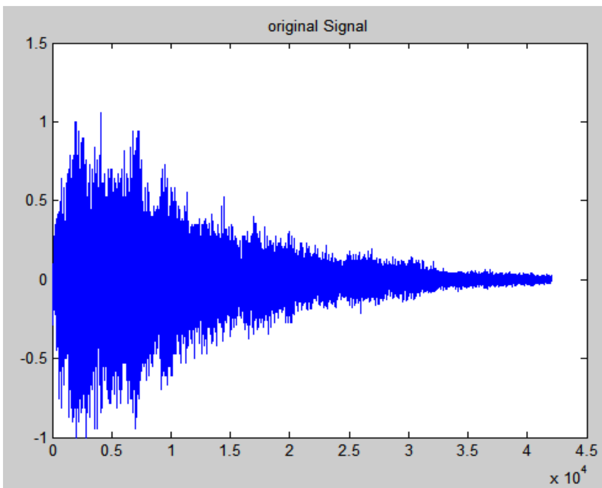

Fig 2: Example of gong sound signal

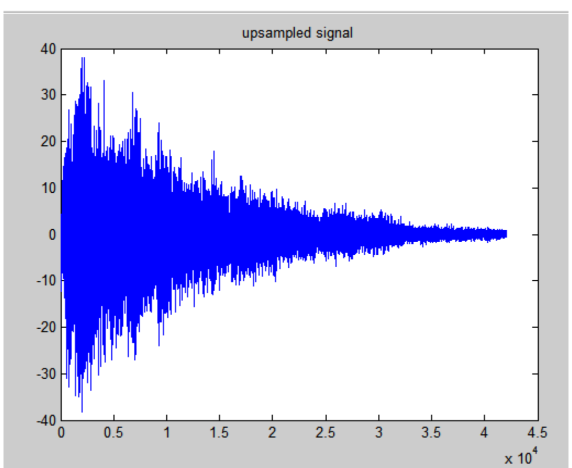

Fig 3: Up sampled gong sound signal

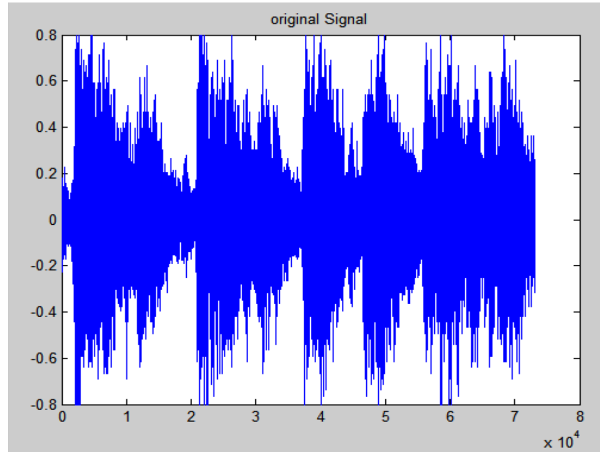

Fig 4: Example of Handel sound signal

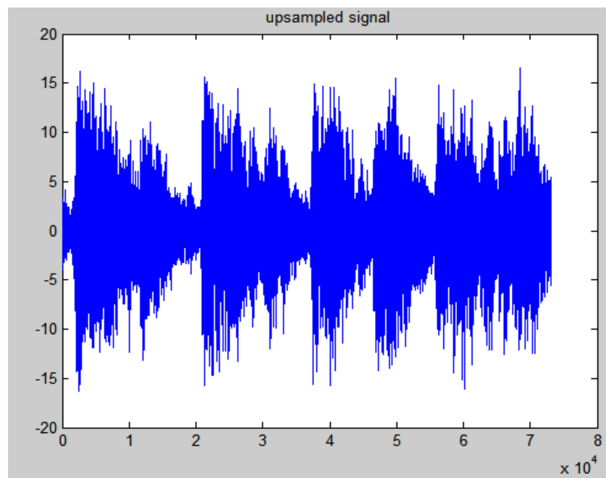

Fig 5: Up sampled Handel sound signal

4. Conclusion

PSO is very useful optimization technique that exhibits good convergence property and able to approximate the filter coefficients in lesser number of iterations. In this paper FIR filter is designed to approximate prescribed specifications of magnitude with respect to the coefficients of the transfer function. Recently most optimization techniques were formulated in terms of minimizing and maximizing the objective function but in this paper PSO algorithm with desired fitness is employed with some modifications to approximate the desired response. The designed filter is then applied to upsample an audio signal with the custom shaped FIR low pass filter. PSO algorithms can be implemented to optimize polyphase FIR filters in future.

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