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Digital FIR Filter Design by PSO and its variants Attractive and Repulsive PSO(ARPSO) & Craziness based PSO(CRPSO)

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Abstract: Digital filters play a major role in signal processing that are employed in many applications such as in control systems, audio or video processing systems, noise reduction applications and different systems for communication. In this regard, FIR filters are employed because of frequency stability and linearity in their phase response. FIR filter design requires multi-modal optimization problems. Therefore, PSO (Particle Swarm Optimization) algorithm and its variants are more adaptable techniques based upon particles' population in the search space and a great option for designing FIR filter. PSO and its different variants improve the solution characteristic by providing a unique approach for updating the velocity and position of the swarm. An optimized set of filter coefficient is produced by PSO and its variant algorithms which gives the optimized results in passband and stopband. In this research paper, Digital FIR filter is effectively designed by using PSO Algorithm and its two variants ARPSO and CRPSO in MATLAB. The outcomes prove that the filter design technique using CRPSO is better than filter design by PM algorithm. PSO and ARPSO Algorithms in the context of frequency spectrum and RMS error

***Keywords**: Craziness based Particle Swarm Optimization (CRPSO), Attractive and Repulsive Particle Swarm Optimization (ARPSO), Particle Swarm Optimization (PSO), Lowpass filter*

I. INTRODUCTION

Digital filter permits certain frequencies to pass unaffected, while totally preventing others. (IIR) Infinite Impulse Response filters and (FIR) Finite Impulse response filters are two types of digital filter, choosing any one of these two filter depends upon relative advantages and particular applications. FIR filters are linear in phase response and have no phase distortion, always stable and their output signal is noiseless signal, that is required in most of the applications of image and signal processing, interface and noise reduction, telephone echo cancellation and restoration of distorted signals. Different methods are available for FIR filter design. Designing FIR filter by using Window technique is often used but this technique is not very much able to manage the frequency response in various band of frequencies [1].

FIR filter design using PM algorithm is an ordinary technique, but this technique has got drawback in terms of computational complexity and high pass band ripples [2], [3]. So, it is great for designing FIR filter using optimization algorithms due to less root mean square (RMS) error between ideal response of the filter and desired response of the filter [3]. For optimum design of filter, several efforts have been done like Genetic Algorithm (GA) [3], Differential Evolution Algorithm [4], Particle Swam Optimization (PSO) [5] are employed. These algorithms are fairly effective and provide a good control of high stopband attenuation in addition to performance constraints. Genetic Algorithm (GA) gives a better outcome in terms of local optimum but failed to provide global optimum result. Hence, Particle Swam Optimization algorithm is capable to crack this problem [6]. PSO algorithm gives the better solution as compared to Genetic algorithm, PSO algorithm provides higher processing time and speed of a single iteration for all optimization troubles instead of genetic algorithm [7].

The drawback of the Particle Swam Optimization algorithm is that it can stuck in local optima and it can be influenced by stagnation problems and premature convergence [8].

Therefore, to advance the performance of Particle Swam Optimization, different search techniques has been employed by researchers, termed as variants of Particle Swam Optimization (PSO). Researchers introduce new parameters like inertia weight, constriction factor and different changes in velocity equation in terms of parameters.[9]

This research paper describes digital FIR low pass filter design using two variants of PSO- Attractive and Repulsive PSO (ARPSO) and Craziness based PSO (CRPSO).

FIR low pass filter design with conventional approaches involve a large no of coefficients if no phase distortion or sharp cutoff in output signal is mandatory. Resulting, actual filter response is not more close to desired filter response within given specifications of filter [10],[11]. So, in this research FIR low pass filter designed using PSO, ARPSO and CRPSO algorithms in MATLAB; output of PSO, ARPSO and CRPSO is a set of optimized coefficients h(n). The main objective is to efficiently design FIR low pass filter using PSO algorithm, ARPSO algorithm and CRPSO algorithm in MATLAB and to compare the effectiveness and performance of these three algorithms and propose the optimum solution on the basis of their performance.

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II. DESIGN FIR FILTER USING PSO, ARPSO & CRPSO

FIR Low pass filter designing techniques and PSO algorithm and its variants discussed in this section

A. Designing FIR Low Pass Filter

In digital signal processing, FIR filters are non-recursive filters taking a fixed no. of coefficients. It depends upon previous information of input, not on previous information of output [12]. The response of frequency for desired filter is:

$$H_d(e^{j\omega}) = \sum_{n=0}^{N} h[n]e^{-j\omega n} \quad (1)$$

where, N represents filter order with filter length of N+1 and h[n] denotes impulse response of filter.

Ideal LP filter response is defined as:

$$H_i(e^{j\omega}) = \begin{cases} 1, & for\ 0 \le w \le w_c \\ x, & otherwise \end{cases} \quad (2)$$

where w_c represents the cut off frequency of LP FIR filter. The obtained filter is first designed by PM (Perks-MacCallum) algorithm, it gives several ripples in the stop band response of output signal, for sharp cutoff a large no of coefficients are required. Hence, PSO and its variant algorithms are employed to solve this issue by reducing an error in actual filter and Ideal filter while utilizing same number of coefficients. This error can be computed as:

$$E(w) = \left[\left|\left(H_i(e^{j\omega}) - H_d(e^{j\omega})\right)\right|\right] \quad (3)$$

$H_i(e^{jw})$ shows frequency response of an ideal filter and $H_d(e^{jw})$ is a desired filter frequency response.

III. PSO ALGORITHM & IT'S VARIANTS

A. PSO (Particle Swarm Optimization) Algorithm

PSO algorithm is an optimization method used to find the best way of a given problem in the search space that is required to maximize a particular objective [13]. This powerful global method was given by R. C. Eberhart and Kennedy in 1995, which is based upon the social behavior of the bird flocking or fish schooling [14],[15]. This technique can easily solve problems related with optimization. In this paper PSO algorithm used to reduce the error by optimizing the coefficients of FIR filter. PSO is an iterative algorithm, in which particles are initialized with arbitrary positions. For every iteration, the error fitness value for every particle *i* is measured by fitness function in the search space of a given problem. Afterwards, velocity of every particle *i* is calculated, that is affected by the particle's personal experience including the experience of its neighbor particle. The calculated velocity of every particle is then employed to update the position of particle which describes coefficients of the filter. Velocity update formula for each particle is calculated as:

$$v_i^{t+1} = w.v_i^t + c_1.r_1.(p_i^t - x_i^t) + c_2.r_2(p_g^t - x_i^t) \quad (4)$$

The position update formula for each particle is:

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (5)$$

where t shows the index of current time, t+1 shows subsequent iterations, r_1 and r_2 are uniformly distributed random numbers, w is inertia coefficient, c_1 is cognitive acceleration factor, c_2 is social acceleration factor, p_i shows the particle's best position and p_g is best position of the swarm.

Designing steps of PSO:

Step I. Define specification of filter, error fitness function, swarm size and set the boundaries in terms of maximum and minimum value of coefficient.

Step II. Initialize particles' population array to random positions and their certain velocities in search space.

Step III. Evaluate error fitness function value according to (3)

Step IV. Update velocity according to (4) and update the position by adding this velocity in (5)

Step V. Reevaluate the fitness function value and compare with its pbest and gbest.

Step VI. Iterate continuously from step II to V until maximum no of iterations or minimum error criteria condition is reached.

Step VII. Result is set of the optimized coefficients of desired filter.

B. ARPSO (Attractive and Repulsive PSO)

For improving the performance of PSO, a novel method called ARPSO Attractive and Repulsive PSO is proposed in to solve the issue of premature convergence [16]. This method uses the wo phases named attractive and repulsive and it introduces a diversity measure factor. This factor is used to control the swarm. In the attraction phase, diversity decreases due to swarm's contraction, but in the repulsion phase the swarm is expanding hence diversity increases[17]. In order to set the direction of the swarm use the following function

if (dir < 0 && diversity > $\boldsymbol{d_{high}}$) then dir = 1
if (dir > 0 && diversity < $\boldsymbol{d_{low}}$) then dir = -1 (6)

Diversity of the swarm can be calculated as:

$$\text{Diversity(S)} = \frac{1}{|s|.|L|} \sum_{i=1}^{|s|} \sqrt{\sum_{i=1}^{N}\left(p_{ij} - \overline{p_j}\right)^2} \quad (7)$$

Where, $|s|$ represents swarm's size, $|L|$ is Largest diagonal length of space, $\boldsymbol{p}_j$ represents to j^{th} value of the average point $\overline{p}$, and $\boldsymbol{p}_{ij}$ represents to j^{th} value of i^{th} particle and N is dimension of a problem.

Therefore, formula for velocity update (4), is modified by multiplying *dir* with last two terms.

This decides the attraction or repulsion of the particles and is given as:

$$v_i^{t+1} = w.v_i^t + \text{dir}\,(c_1.r_1.(p_i^t - x_i^t) + c_2.r_2(p_g^t - x_i^t))$$

Designing steps of ARPSO:

Step I. Define specification of filter, error fitness function, swarm size and boundaries set in terms of maximum and minimum value of coefficient.

Step II. Initialize the array of particles' population to arbitrary positions and their certain velocities in search space.

Step III. Evaluate error fitness function value according to (3).

Step IV. Set Direction according to (6) by calculating the diversity using (7).

Step V. Update velocity according to (8) and update the position by adding this velocity in (5).

Step VI. Reevaluate the fitness function value and compare with its pbest and gbest.

Step VII. Iterate incessantly from step II to VI until maximum no of iterations or minimum error criteria condition is reached.

Step VIII. Result is set of the optimized coefficients of desired filter.

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C. Craziness based PSO Algorithm (CRPSO).

Particle swarm optimization technique is updated with the following changes. This variant of the PSO is known as CRPSO Craziness based particle swarm optimization [18].

The formula for velocity of this variant of PSO is well-defined as:

$$v_i^{t+1} = r_2.sign(r_3).v_i^t + (1-r_2).c_1.r_1.(p_i^t - x_i^t) + (1-r_2).c_2.(1-r_1).(p_g^t - x_i^t) \quad (09)$$

r1,r2 and r3 are uniformly distributed random numbers and the function (r3) is given as

$$sign(r_3) = \begin{cases} -1, & \text{where } r_3 \le 0.05 \\ 1, & \text{where } r_3 > 0.05 \end{cases} \quad (10)$$

If the two independent random parameters r1 and r2 of (4) are in large values, then personal behavior as well as social behavior of particles is overused and particle is switched so far from the favorable area. And if r1 and r2 are in small values then personal behavior as well as social behavior of particles is not fully used hence, convergence speed of this method is decreased [19].

So, rather than employing two independent random numbers r1 and r2, a single r1 is selected. Smaller value of r1 leads to the large value of (1 - r1) and contrariwise. Furthermore, additional random constraint r2 is employed to manage the equilibrium between local and global searches of particles.

After the position of the particle is updated according to (5), in some rare cases of particles' moving towards target, a particle may not move to a place promising for target. Rather than this, it could be moving towards a place that is in reverse direction of the auspicious place. In this situation, the direction of the particle's speed must be reversed to move it back to the expected place. So, for this reason a function sign(r3) is employed. In moving of particles toward target, any particle often switches its directions unexpectedly. So, it is well-defined by a ''craziness'' term exhibited in the algorithm by employing a craziness variable. A craziness factor is presented for particle's predefined craziness probability for sustaining the diversity of particles. Thus, the velocity of particle is crazed as:

$$v_i^{t+1} = v_i^{t+1} + P(r_4).sign(r_4).v^{craziness} \quad (11)$$

where r_4 is consistently distributed random number uniformly chosen from the interval [0, 1] , $v^{czariness}$ is a uniformly chosen random number from the boundary of maximum and minimum velocities of particle , $P(r_4)$ and $sign(r_4)$ are functions defined as:

$$P(r_4) = \begin{cases} 1, & \text{when } r_4 \le P_{cr} \\ 0, & \text{when } r_4 > P_{cr} \end{cases} \quad (12)$$

$$sign(r_4) = \begin{cases} -1, & \text{where } r_4 \ge 0.5 \\ 1, & \text{where } r_4 < 0.5 \end{cases} \quad (13)$$

P_{cr} is predefined craziness probability.

Designing steps of CRPSO:

Step I. Define specification of filter, error fitness function, swarm size and set the boundaries in terms of maximum and minimum value of coefficient.

Step II. Initialize particles' population array to random positions and their certain velocities in search space.

Step III. Evaluate error fitness function value according to (3)

Step IV. Update velocities according to (9) and (11) and update the position by adding these velocities in (5)

Step V. Reevaluate the fitness function value and compare with its pbest and gbest.

Step VI. Iterate continuously from step II to V until maximum no of iterations or minimum error criteria condition is reached.

Step VII. Result is set of optimized coefficients set of desired filter.

IV. PROPOSED METHODOLOGY

FIR low pass filter is designed for given specifications in MATLAB 2018a and output is in terms of coefficients. These coefficients are then optimized by deigning FIR low pass filter using PM algorithm, PSO and its two variant algorithm (ARPSO and CRPSO). Best solution is suggested on the basis of the results obtained by these algorithms.

V. RESULTS AND DICSUSSIONS

This section determines the usage of PSO, ARPSO and CRPSO algorithms for designing a 20^{th} order FIR low pass fitter.

The FIR low pass filter to be designed, having following specifications: Passband ripples (δ_p) =0.1, Stopband ripples (δ_s) = 0.01, frequency for passband (ω_p) =0.45 and frequency for stopband (ω_s) = 0.55.

Table-I presents the values of the parameters that are used during this whole work.

Initially FIR LP filter is designed by PM algorithm and then filter coefficients optimized by applying PSO algorithm and its variants ARPSO and CRPSO. Fig. 1 and 2 shows the frequency response of FIR low pass filter in dB designed by Ideal, PM, PSO, ARPSO and CRPSO algorithm. Designing FIR low pass filter using CRPSO algorithm gives better response (near to ideal response) as compared to other algorithms. Fig. 3 and 4 shows the pass band and stop band ripple response of designed FIR Low pass filter using PM, PSO, ARPSO and

CRPSO Algorithm. Its clear indicate that CRPSO gives better stop band attenuation.

Table- I: Parameters used in PSO, ARPSO and CRPSO

Parameters	PSO	ARPSO	CRPSO
Filter Order	20	20	20
Swarm Size	250	520	250
Accelarating Factor (c1)	2.05	2	2.05
Accelarating Factor (c2)	2.05	2	2.05
Inertia weight (w)	0.65	0.65	0.65
Maximum no of Iteration	500	500	500
dlow	-	0.25	-
dhigh	-	1.5	-
Vczariness	-	-	0.0001
Pcr	-	-	0.03

Table III presents the coefficients obtained from PM, PSO, ARPSO and CRPSO algorithm.

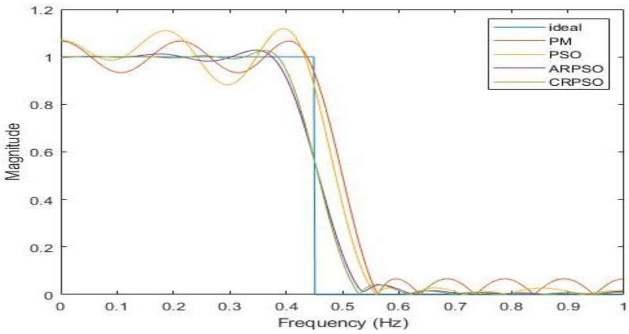

Figure 1. Normalized frequency response of FIR low pass filter by using Ideal PM, PSO, ARPSO and CRPSO

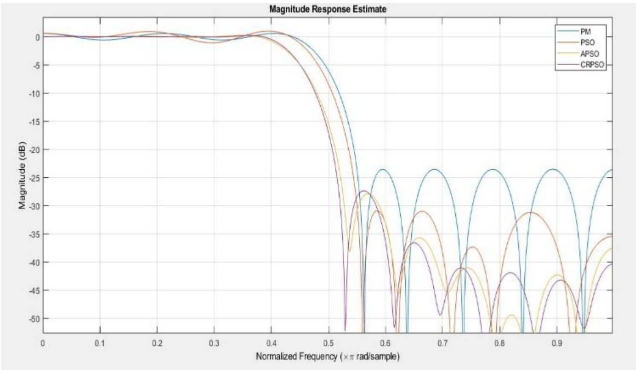

Figure 2. Frequency response in dB of FIR Lowpass filter using Ideal PM, PSO, ARPSO and CRPSO Algorithm

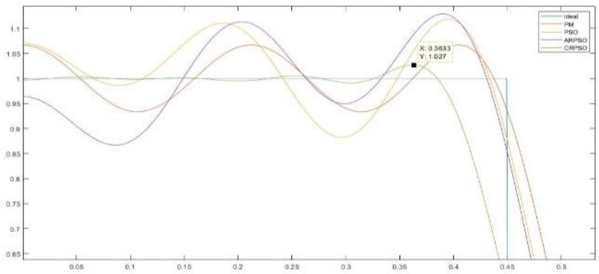

Figure 3. Normalized pass band ripples

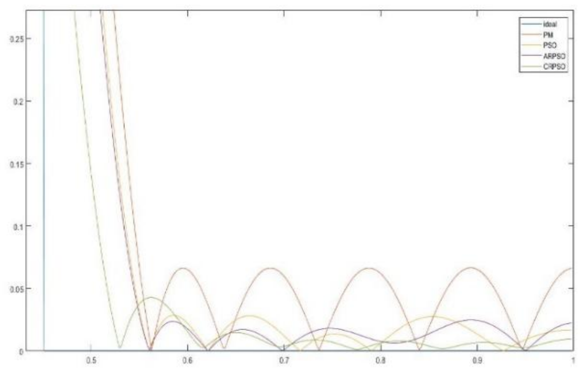

Figure 4. Normalized Stop band ripples

It's observed that with the increase in swarm size, stop band ripples are decreased at great extent and by increasing the number of iteration for PSO, ARPSO and CRPSO algorithm gives the sharp cutoff response which is desirable, while CRPSO gives the better response among all. Furthermore, RMS error is calculated as shown in table II, it indicates that RMS error of ARPSO and CRPSO is almost same at swarm size equals to 250 and number of iteration equals to 500.

Table- II: RMS Error

Algorithm	RMS Error
PM	0.277803522487745
PSO	0.256159064083106
ARPSO	0.213097751374587
CRPSO	0.212422902231920

Table- III: FIR Low pass filter coefficients

H(n)	PM	PSO	ARPSO	CRPSO
H(1)	0.000016462026203	0.022587593788748	0.00803439487039966	0.0276902020329154
H(2)	0.048051046361716	0.034243459454764	-0.0049398310235559	0.0423885626214059
H(3)	-0.00002345544888	-0.01708657717864	-0.035705199453981	0.00836302705096084
H(4)	-0.03691143268907	-0.04613129539532	-0.0336607635466447	-0.0347660527364396
H(5)	-0.00001480425748	0.000229126085020	0.0221611461748543	-0.0191431815201785
H(6)	0.057262893095235	0.058644950198106	0.0370939850750953	0.0230664733408076
H(7)	0.000000677226645	-0.006546001812412	-0.0483651164415937	0.0106260805454262
H(8)	-0.10217298340392	-0.097122365891821	-0.122671054525694	-0.0261392165771706
H(9	0.000011850968750	0.013760466527049	-0.0043819753332063	0.0546379548333843
H(10)	0.316962289494363	0.322156879042563	0.274159966374112	0.276885930432907

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H(11)	0.500018538901555	0.500748972249363	0.451732309129871	0.439445184250555
H(12)	0.000016462026203	0.022587593788748	0.345366069444934	0.338393807987281
H(13)	0.048051046361716	0.10.03424345945476 4	0.0852028329919949	0.0517033349267616
H(14)	-0.00002345541488	-0.017086577157864	-0.0618884304011501	-0.140980843572176
H(15)	-0.03691114326897	-0.046131029539532	-0.0229997389555123	-0.0948493034802623
H(16)	-0.00001480425748	0.000229126085020	0.0484897283766279	0.0474934015245734
H(17)	0.057262893095235	0.058644950198106	0.0382124416731287	0.0838683923403714
H(18)	0.000000677226645	-0.006546001812412	-0.0098246864306854	0.0065585712715817 3
H(19)	-0.10217298340312	-0.097122365891821	-0.0072333666065340	-0.0530785181555071
H(20)	0.000011850968750	0.013760466527049	0.0210001002517944	-0.0393465654987887
H(21)	0.316962289494363	0.322156879042563	0.0196929657424626	-0.0060747394741557

VI. TEST SIGNAL RESULTS

Initially the test signal (sinusoidal signal) was generated in MATLAB workspace with sampling freq. 20000Hz, signal freq. 4500Hz as shown in Fig. 5 and White Gaussian Noise is added to original signal with Signal to Noise Ratio (SNR=1). Noisy signal is used as input of FIR filter. Initially noisy signal is applied to the original filter designed by PM algorithm, the coefficients of FIR LP filters designed by PM, PSO, ARPSO and CRPSO are shown in table III and the output filtered signal is shown in fig. 8 which contains additional noise existing in original input signal. However same input signal is applied to FIR LP filter designed by PSO, ARPSO and CRPSO algorithm, better output filtered signal is obtained and RMS error is also reduced as shown in table II, while we used same model as shown in Fig. 1&2 but filter designed by CRPSO gives the optimized coefficients and better output signal & RMS error is also reduced.

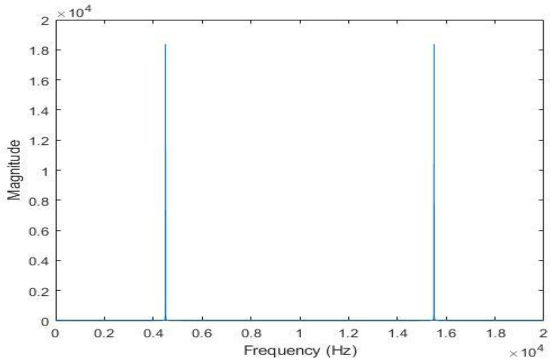

Figure 5. Frequency Spectrum of Sinusoidal Test Signal

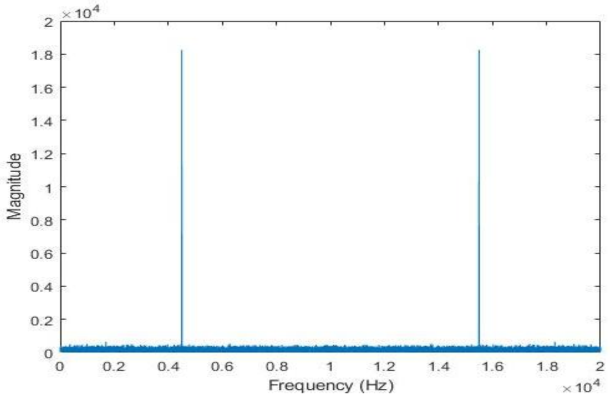

Figure 6. Frequency Spectrum of Noisy Signal

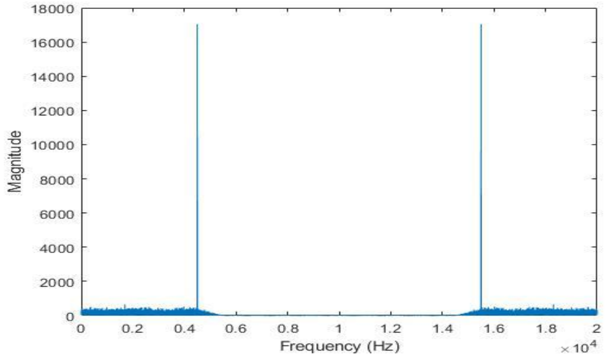

Figure 7. Frequency Spectrum of PM optimized output signal

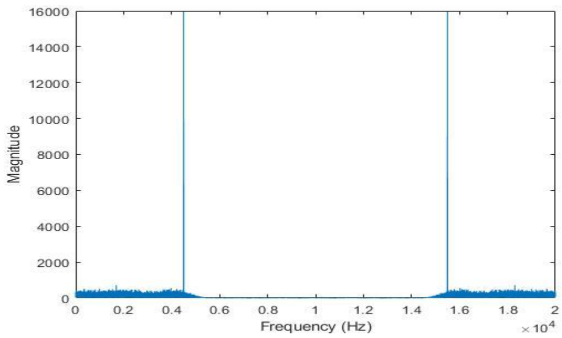

Figure 8. Frequency Spectrum of PSO optimized output signal

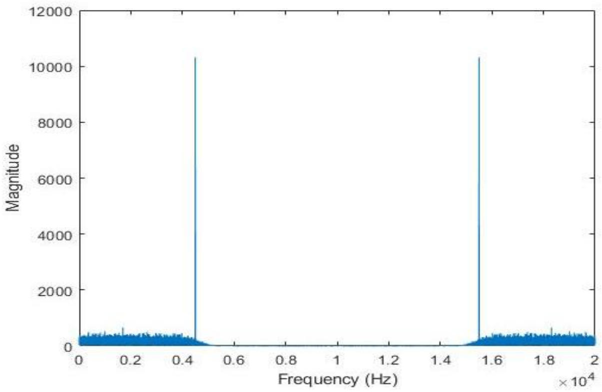

Figure 9. Frequency Spectrum of ARPSO optimized output signal

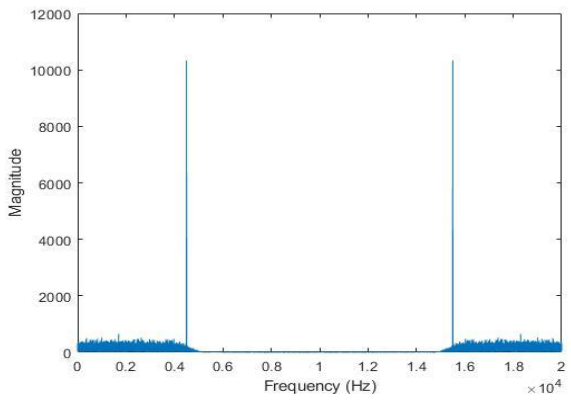

Figure 10. Frequency Spectrum of CRPSO optimized output signal

VII. CONCLUSION

So far, PSO and its variants have been used for different applications individually. In this research, PSO and its two variants (ARPSO and CRPSO) have been used for one specific application (FIR lowpass filter) and their performances are comparatively analyzed. This work has presented the design of FIR Low pass filter in MATLAB with given specification by PM, PSO, ARPSO and CRPSO algorithms. It is found that PSO, ARPSO and CRPSO are ease to implement in context of coding as well as in parameter selection. Comparison of performance and effectiveness of PSO, ARPSO and CRPSO algorithm has been made, from the results its found that the performance of CRPSO is better than ARPSO and PSO and PM algorithm in the context of RMS error. So, designing FIR low pass filter using CRPSO and ARPSO algorithm is more applicable in all those applications where FIR filters are employed. Furthermore, by utilizing these same resources this whole work can be implemented on hardware to get more effective results.

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