

Implementation of GOA to Non-Uniform PRI of SFPT for improving Resolution in Radar



K. Ravi Kumar, P. Rajesh Kumar, G. Manmadha Rao, B. Chinna Rao

Abstract - Pulse compression techniques are mostly used for increasing range resolution in radar systems. Stepped Frequency Pulse Train (SFPT) signal is well suitable in pulse compression techniques. The Pulse Repetition Interval (PRI) of the SFPT is varied to avoid the blind speed and in Counter Measures. Here, evolutionary algorithms are used to optimize non-uniform PRI sequence of SFPT signal for getting better resolution. The PSLR (Peak Sidelobe Ratio) and ISLR (Integrated Sidelobe Ratio) are the performance measures of the signal. The non-uniform PRI sequence is optimized by Differential Evolutionary Algorithm (DE) but it has several drawbacks including unstable convergence in the last period and easy to drop into regional optimum. To overcome this, Grasshopper Optimizer Algorithm (GOA) is used in this paper for increasing the PSLR of Non uniform PRI SFPT signal.

Index Terms: PSLR, ISLR, PRI, DE Algorithm, GOA

I. INTRODUCTION

Wide band signals are required for high resolution radars. As conventional hardware is not found to be suitable. Pulse compression technique [1] has been adopted to give the benefits of high energy long pulses and an optimum resolution of narrowband pulses. To obtain an adequate resolution, stepped frequency pulse train (SFPT) is found useful [2]. Fig. 1, shows SFPT signal having N pulses with width τ_p and repetition period of τ_r . The frequency step between the consecutive pulses is marked by Δf and the overall band width is denoted by B. PRI is the time between two adjacent pulses [3]. PRI is a very important parameter in radar technology because it is used to find the maximum range of a target (R_{max}) and maximum Doppler velocity (V_{max}) accurately. Low PRI increases range resolution. Therefore mostly uses low PRI and high PRI for search radar [4]. Non-uniform PRI [5] can also be used as it doesn't have any severe theoretical problems. A uniform PRI waveform is a sample pulse of the target echo signal especially for the Doppler shifted echo signals from targets.

In a uniform PRI all samples after pulse transmission contains the same mix of scatterer returns [6]. But in a non-uniform PRI the mixture of scatterers to identify in a sample becomes more complex. The problem can be avoided if a minimum PRI value is restricted to be unambiguous.

Applications can use to implement a non uniform PRI if chooses a minimum PRI values to avoid these ambiguities. SFPT PRI pulse train is used for improving PSLR and ISLR [7]. For further improvements of these parameters, DE algorithm with non-uniform PRI SFPT signal was applied for different number of pulses [8]. The simulation results show better PSLR and ISLR but it has unstable convergence in the last period. To overcome this drawback in this paper Grasshopper optimization algorithm is used to optimize PRI for better PSLR value.

In this paper, section II analyses the SFPT signal. Section III elaborates on the SFPT with DE algorithm. The results of SFPT with GOA have been discussed in section IV followed by conclusions in section V.

II. STEPPED FREQUENCY PULSE TRAIN (SFPT) ANALYSIS

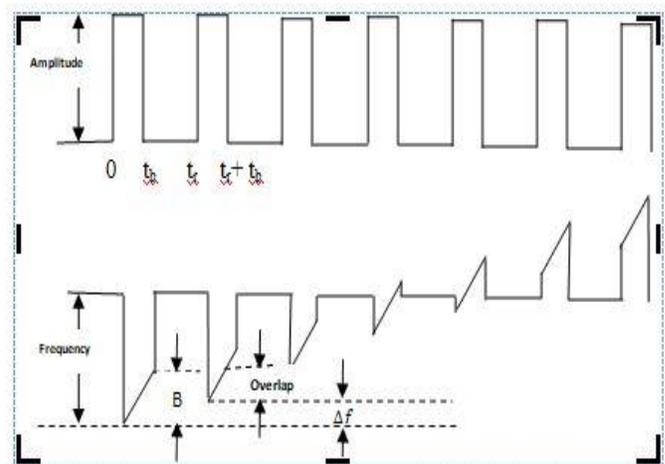


Fig. 1. Stepped Frequency Pulse Train

The SFPT consists of N pulses, each of duration τ_p and the time between two pulses is τ_r . The envelope of unmodulated pulse is given by [9, 10].

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Implementation of GOA to Non-Uniform PRI of SFPT for improving Resolution in Radar

$$u(t) = \frac{1}{\sqrt{t_b}} \text{rect}\left(\frac{t}{t_b}\right) \quad (1)$$

The complex envelope of LFM pulse is given by

$$u_1(t) = \frac{1}{\sqrt{t_b}} \text{rect}\left(\frac{t}{t_b}\right) \exp(j\pi kt^2) \quad (2)$$

Where k is the frequency slope of LFM signal and is defined as

$$k = \pm \frac{B}{\tau_p} \quad (3)$$

B is bandwidth of single LFM pulse. The value of k is positive but the analysis is applicable to negative value of k .

The ACF of $u_s(t)$ is given by

$$|R(\tau)| = \left| \left(1 - \frac{|\tau|}{t_b}\right) \text{sinc}\left[B\tau\left(1 - \frac{|\tau|}{t_b}\right)\right] \right| \left| \frac{\sin(N\pi\tau\Delta f)}{N\sin(\pi\tau\Delta f)} \right| \quad (4)$$

A closed-form expression of the ambiguity function of non-uniform PRI SFPT signal is given by

$$\chi(\tau, \nu) = \frac{1}{N} \sum_{q=-(N-1)}^{N-1} \left| \chi_1\left(\tau - qt_{|r|}, \nu\right) \right| \left| \frac{\sin[\pi\nu(N - |q|t_{|r|})]}{\sin(\pi\nu t_{|r|})} \right| \quad (5)$$

III. DIFFERENTIAL EVOLUTION ALGORITHM

Differential Evolution (DE) Algorithm has been introduced to find out the optimized parameters with good convergence for maximizing the performance measure [11]. DE is a stochastic search algorithm that was originally motivated by the mechanism of natural selection, it effectively solves optimization problem with non-smooth objective functions. This is so because DE does not require derivative information. The DE algorithm was first introduced by Storm and Price in 1995 [12]. It generates trial parameter vectors and for every step, mutates vectors by combining weighted random vector differentials to them. If the trial vector is better than target; target vector is replaced by the trial if the cost of the trial vectors in the next generation [13].

The fitness function is used to assign a fitness value to each of the individuals in the population of optimization algorithm. It is the only connection between the physical problem being optimized and the optimization algorithm [14].

A. Simulation results of DE Algorithm

Here, the number of iterations are taken to be 100, pulse width is $0.4\mu\text{s}$, Δf is 2MHz for all the simulations. The ambiguity function plot of optimized SFPT signal using differential Algorithm for $N=6$ is shown in Fig. 2. The optimized PRI sequence obtained for $N=6$ in μs is $\{1.135,$

$8.104, 4.345, 1.021, 3.99, 1.124\}$. The PSLR and ISLR obtained for the ambiguity function in Fig. 2 is -26.65dB and -17.87dB . PSLR maximization plot using DE Algorithm for $N=6$ is shown in Fig. 3.

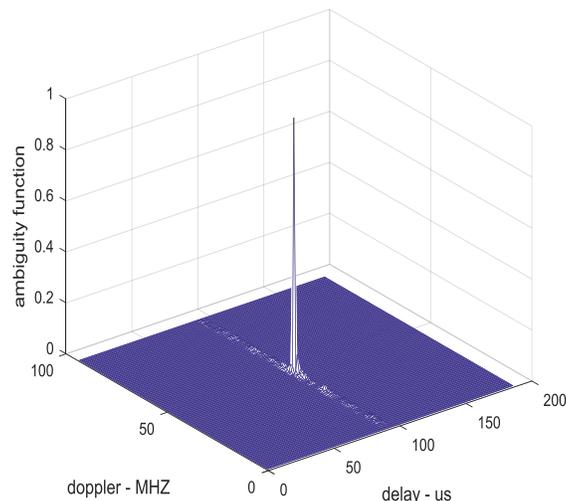


Fig. 2. Ambiguity function plot of optimized non uniform PRI SFPT signal using DE Algorithm for $N=6$

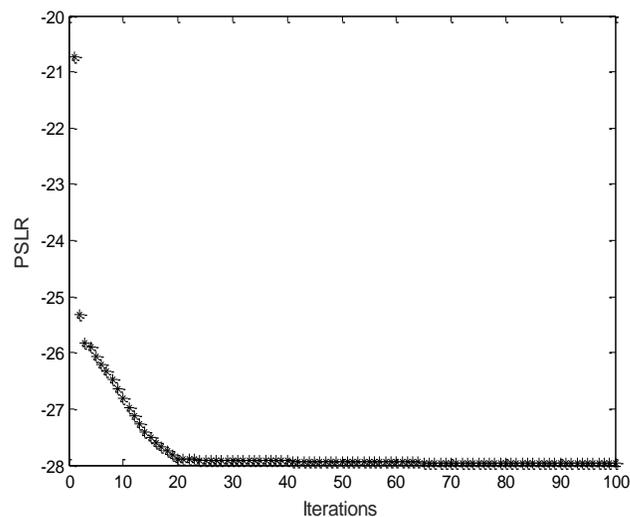


Fig. 3. PSLR maximization plot using Differential Evolution Algorithm for $N=6$.

The ambiguity function plot of optimized SFPT signal using Differential Evolution Algorithm for $N=8$ is shown in Fig. 4. The optimized PRI sequence obtained for $N=8$ in μs is $\{2.96, 8.904, 1.249, 3.804, 2.59, 1.827, 6.43, 4.099\}$. The PSLR and ISLR obtained for the ambiguity function in Fig. 4 is -35.75dB and -28.81dB . PSLR maximization plot using DE Algorithm for $N=8$ is shown in Fig. 5. The ambiguity function plot of optimized SFPT signal using Differential Evolution Algorithm for $N=9$ is shown in Fig. 6.

Implementation of GOA to Non-Uniform PRI of SFPT for improving Resolution in Radar

The optimized PRI sequence obtained for $N=9$ in μs is {4.1348, 5.7923, 3.981, 2.7199, 8.5505, 1.2299, 6.8942, 8.9995, 3.2478}. The PSLR and ISLR obtained for the ambiguity function in Fig. 6 is -42.56dB and -37.89dB. PSLR maximization plot using DE Algorithm for $N=9$ is shown in Fig. 7.

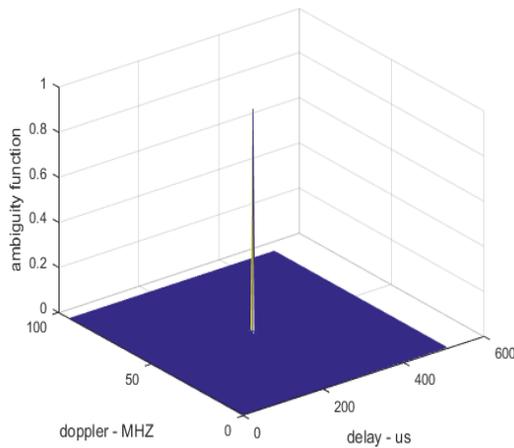


Fig. 4. Ambiguity function plot of optimized non uniform PRI SFPT signal using DE Algorithm for $N=8$

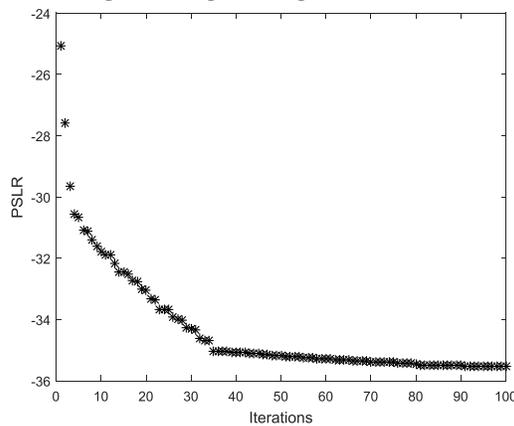


Fig. 5. PSLR maximization plot using DE Algorithm for $N=8$

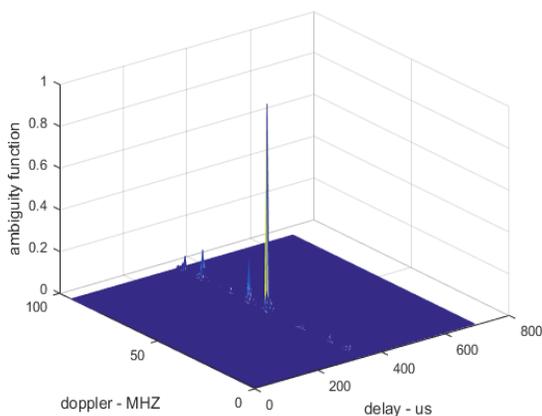


Fig. 6. Ambiguity function plot of optimized non uniform PRI SFPT signal using DE Algorithm for $N=9$.

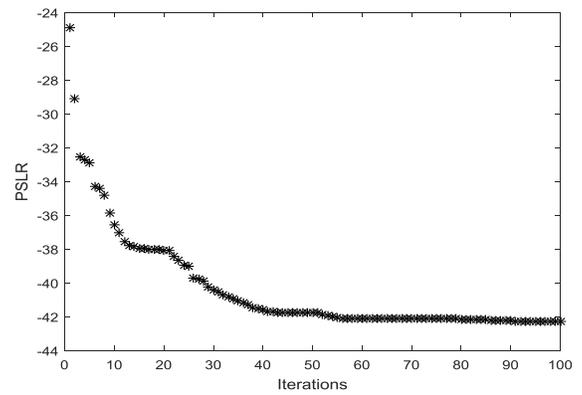


Fig. 7. PSLR maximization plot using Differential Evolution Algorithm for $N=9$

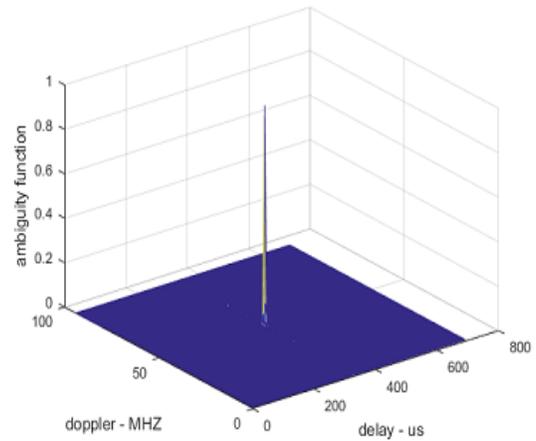


Fig. 8. Ambiguity function plot of optimized non uniform PRI SFPT signal using DE Algorithm for $N=10$.

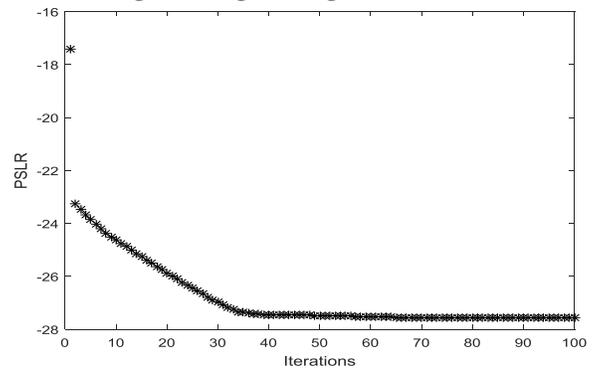


Fig. 9. PSLR maximization plot using Differential Evolution Algorithm for $N=10$

The ambiguity function plot of optimized SFPT signal using Differential Evolution Algorithm for $N=10$ is shown in Fig. 8. The optimized PRI sequence obtained for $N=10$ in μs is {9.5712, 3.7169, 3.8932, 7.1006, 8.999, 2.4723, 8.0235, 5.4394, 4.5895, 3.6079}.

Implementation of GOA to Non-Uniform PRI of SFPT for improving Resolution in Radar

The PSLR and ISLR obtained for the ambiguity function in Fig. 8 is -27.57dB and -19.30dB. PSLR maximization plot using DE Algorithm for N=10 is shown in Fig. 9.

Table-I: PSLR and ISLR of DE Algorithm

No. of Pulses	PSLR(dB)	ISLR(dB)
6	-26.65	-17.87
8	-35.75	--28.81
9	-42.56	-37.89
10	-27.57	-19.30

The PSLR and ISLR values for N=6, N=8, N=9, N=10 are obtained and the values are shown in Table-1. The better value of PSLR is obtained for N = 9.

IV. GRASSHOPPER OPTIMIZATION ALGORITHM

In this section, Grasshopper Optimization Algorithm (GOA) [15] is used which has been proven to benefit from high exploration along with very fast convergence speed. It smoothly balances exploration and exploitation which makes the algorithm capable of handling difficulties of objective search space and outperform other techniques. Grasshoppers are insects and usually seen individually in nature. But they join in one of the largest swarm. In general, nature inspired algorithms follows two steps: 1) Exploration in which the search agents move abruptly. 2) Exploitation where the search agents move locally. These two functions as well as target seeking are performed by grasshoppers naturally. So, a mathematical model for swarming behavior of grasshoppers gives a new effective nature inspired algorithm. In general, GOA algorithm simulates swarming behavior of grasshoppers. In GOA, the possible solution of a given optimization problem is given by the grasshoppers position in the swarm [15-17]. X_i shows position of i^{th} grasshopper and given in Eq. 6

$$X_i = S_i + G_i + A_i \quad (6)$$

Where S_i is the social interaction among grasshopper, G_i is gravity force on i^{th} grasshopper and A_i shows the effect of wind force on i^{th} grasshopper. Although the three components S_i , G_i , A_i fully simulate the movement of grasshoppers, the main component originated from grasshopper themselves is the social interaction which is shown below.

$$S_i = \sum_{\substack{j=1 \\ j \neq i}}^N s(d_{ij}) \hat{d}_{ij} \quad (7)$$

where d_{ij} is the distance between the i^{th} and j^{th} grasshopper and it is calculated as $d_{ij} = |x_j - x_i|$, 'S' is a function to define the strength of social forces and $\hat{d}_{ij} = \frac{x_j - x_i}{d_{ij}}$ is a unit vector from i^{th} grasshopper to j^{th} grasshopper. Where f and l are the intensity of attraction and attractive length scale. The gravity component G in Eq. 6 is given as

$$G_i = -g \hat{e}_g \quad (8)$$

where \hat{e}_g is the unity vector and g is the gravitational constant. The wind force component A_i is given as

$$A_i = u \hat{e}_w \quad (9)$$

where u gives constant drift and \hat{e}_w represents unity vector in the direction of wind. Noe Eq. 6 can be written by including all components as

$$X_i = \sum_{\substack{j=1 \\ j \neq i}}^N s(|x_j - x_i|) \frac{|x_j - x_i|}{d_{ij}} - g \hat{e}_g + u \hat{e}_w \quad (10)$$

Where

$s(d) = fe^{-\frac{d}{l}} - e^{-d}$ and N gives the number of grasshoppers. In order to obtain an accurate approximation of the global optimum, a stochastic algorithm should perform exploration and exploitation. So, we need special parameters to show exploration and exploitation in different stages of optimization. The mathematical model is shown below

$$X_i^d = c \left(\sum_{\substack{j=1 \\ j \neq i}}^N c \frac{ub_d - lb_d}{2} s(|x_j^d - x_i^d|) \frac{x_j^d - x_i^d}{d_{ij}} \right) + \hat{T}_d \quad (11)$$

Where ub_d is the upper bound in the d^{th} dimension, lb_d is the lower bound in the d^{th} dimension. \hat{T}_d is the value of d^{th} dimension in the target and c is a decreasing coefficient to lessen the comfort area, repulsion area and attraction area. Also, the G component is not taken into consideration and the wind direction is always assumed to be towards the target. The inner c which reduces the repulsion or attraction forces between grasshoppers is proportional to the number of iterations and the outer c decreases the search coverage around the target while the iteration count increases. In order to reduce exploration and increase exploitation, the decreasing coefficient c is defined as

Implementation of GOA to Non-Uniform PRI of SFPT for improving Resolution in Radar

$$c = c_{max} - l \frac{c_{max} - c_{min}}{L} \quad (12)$$

Where c_{max} is the maximum value, c_{min} is the minimum value, l is the current iteration and L is the maximum number of iterations. The interesting pattern is the gradual convergence of grasshoppers towards the target over the course of iteration, which is again due to decreasing the factor c . These behaviors will assist the GOA algorithm not to converge towards the target too quickly and consequently not to become trapped in local optima. In the last steps of optimization, however, grasshoppers will converge towards the target as much as possible, which is essential in exploitation. Flow chart of GOA is shown in Fig. 10.

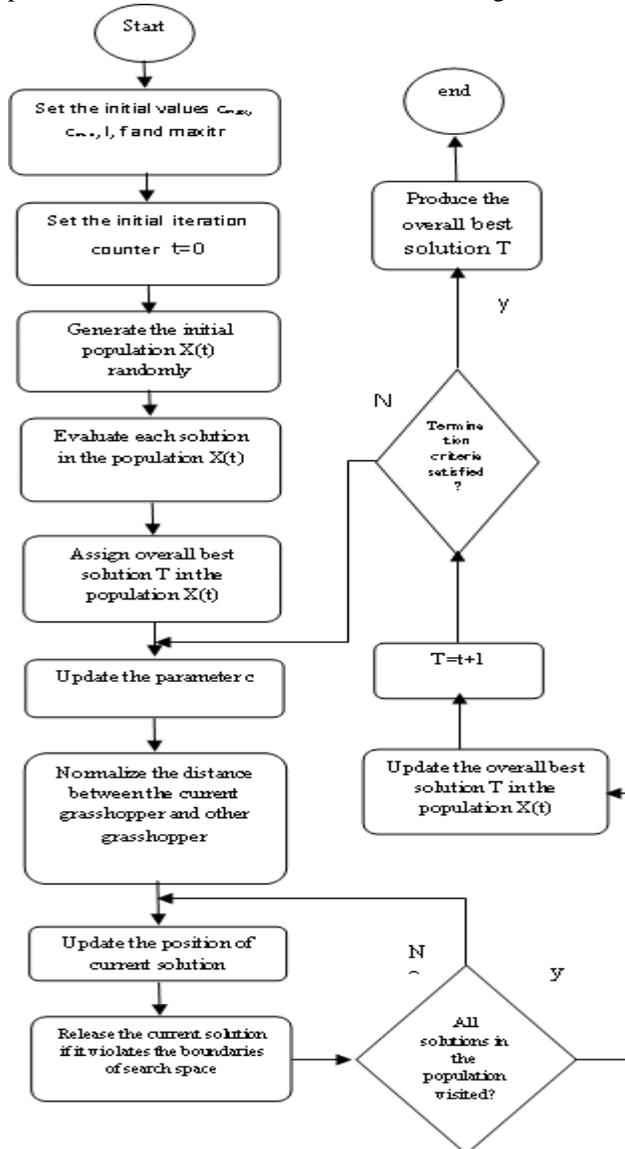


Fig. 10. Flow chart of Grasshopper Optimization Algorithm.

A. Simulation Results of Grasshopper Optimization Algorithm

Here, the number of iterations are taken to be 100, pulse width is $0.4\mu s$, Δf is 2 MHz and the population size is 100 for all the simulations. The ambiguity function plot of optimized SFPT signal using Grasshopper Optimization Algorithm for $N=6$ is shown in Fig. 11. The optimized PRI sequence obtained for $N=6$ in μs is $\{1.1208, 1.1182, 8.1902, 5.4315, 4.1822, 1.4161\}$. The PSLR and ISLR obtained for the ambiguity function in Fig. 11 is -35.05 dB and -26.17 dB. PSLR maximization plot using GOA for $N=6$ is shown in Fig. 12.

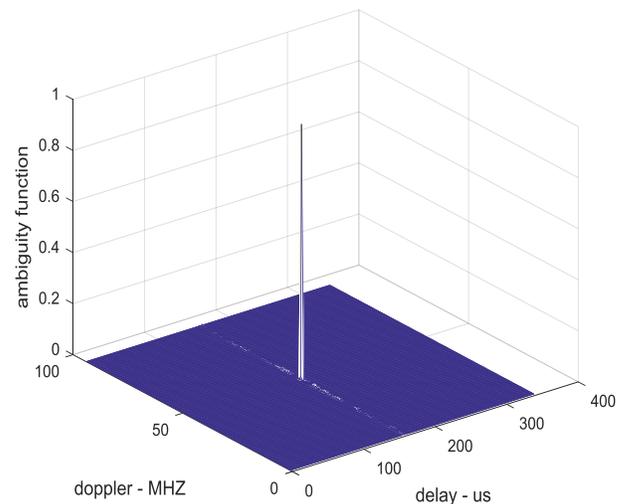


Fig. 11. Ambiguity function plot of optimized SFPT signal using Grasshopper Optimization Algorithm for $N=6$.

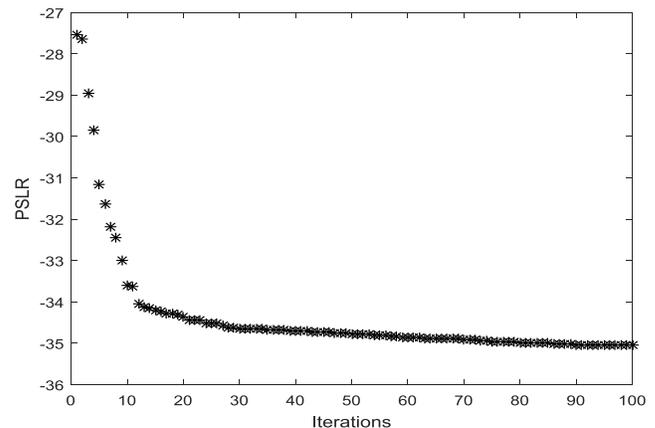


Fig. 12. PSLR maximization plot using Grasshopper Optimization Algorithm for $N=6$.

The ambiguity function plot of optimized SFPT signal using Grasshopper Optimization Algorithm for $N=8$ is shown in Fig. 13.

Implementation of GOA to Non-Uniform PRI of SFPT for improving Resolution in Radar

The optimized PRI sequence obtained for $N=8$ in μs is $\{3.87, 8.075, 0.105, 8.68, 1.741, 4.4728, 2.8659, 6.2134\}$. The PSLR and ISLR obtained for the ambiguity function in Fig. 13 is -45.55dB and -23.85dB . PSLR maximization plot using GOA for $N=8$ is shown in Fig. 14.

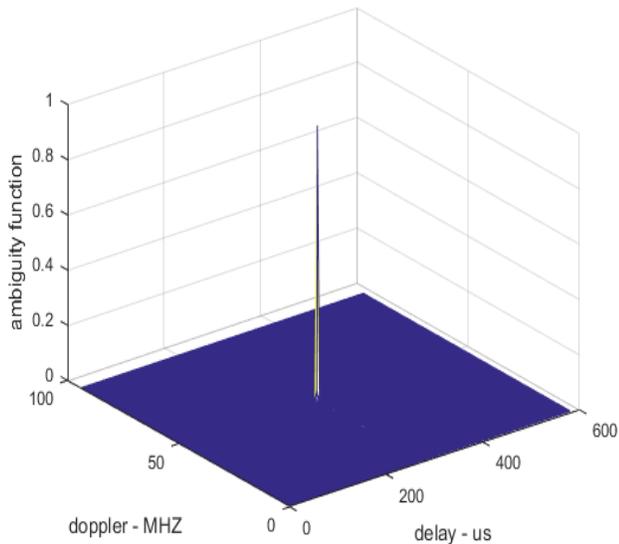


Fig. 13. Ambiguity function plot of optimized non uniform PRI SFPT signal using GOA for $N=8$.

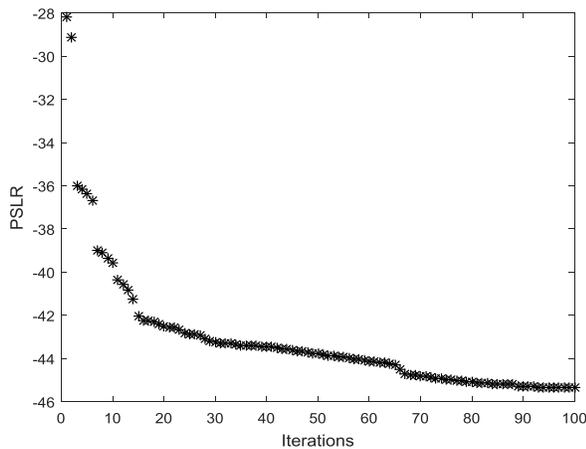


Fig. 14. PSLR maximization plot using Grasshopper Optimization Algorithm for $N=8$.

The ambiguity function plot of optimized SFPT signal using Grasshopper Optimization Algorithm for $N=9$ is shown in Fig. 15. The optimized PRI sequence obtained for $N=9$ in μs is $\{1.0374, 5.5398, 4.213, 8.9999, 3.3495, 6.739, 2.6968, 3.5589, 8.1461\}$. The PSLR and ISLR obtained for the ambiguity function in Fig. 15 is -47.70dB and -32.06dB . PSLR maximization plot using GOA for $N=9$ is shown in Fig. 16.

The ambiguity function plot of optimized SFPT signal using Grasshopper Optimization Algorithm for $N=10$ is shown in Fig. 17. The optimized PRI sequence obtained for $N=9$ in μs is $\{5.398, 1.3444, 5.3137, 3.1963, 8.9995, 7.8646, 4.3112, 7.0536, 3.2449, 2.066\}$. The PSLR and ISLR obtained

for the ambiguity function in Fig. 17 is -39.82dB and -22.26dB . PSLR maximization plot using GOA for $N=10$ is shown in Fig. 18.

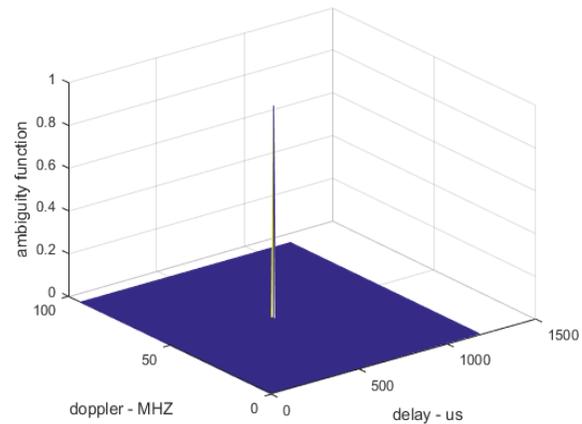


Fig. 15. Ambiguity function plot of optimized non uniform PRI SFPT signal using GOA for $N=9$.

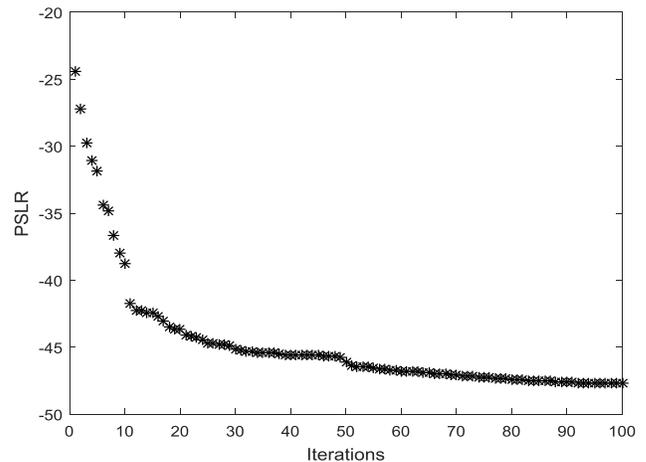


Fig. 16. PSLR maximization plot using Grasshopper Optimization Algorithm for $N=9$.

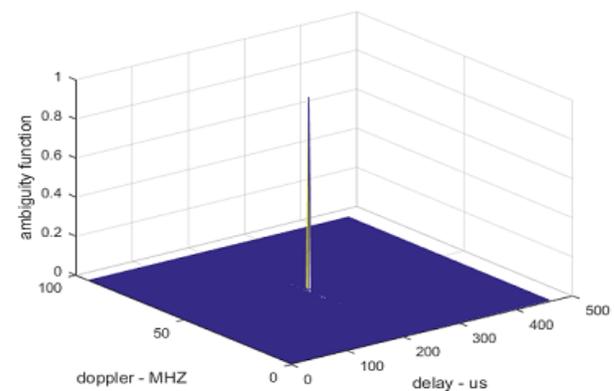


Fig. 17. Ambiguity function plot of optimized non uniform PRI SFPT signal using GOA for $N=10$.

Implementation of GOA to Non-Uniform PRI of SFPT for improving Resolution in Radar

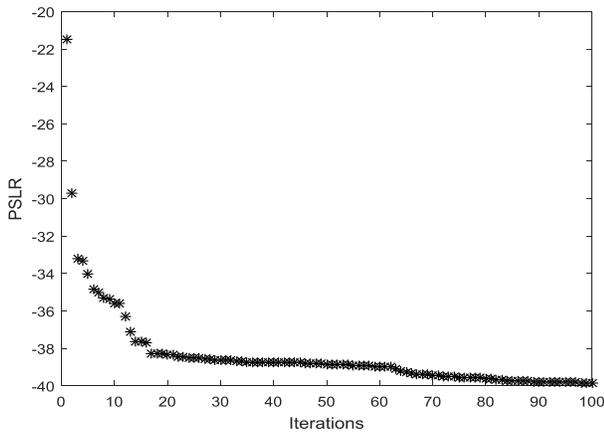


Fig. 18. PSLR maximization plot using Grasshopper Optimization Algorithm for N=10.

The PSLR and ISLR values for N=6, N=8, N=9, N=10 are obtained and the values are compared in table-II. The better value of PSLR is obtained for N=9.

Table-II: PSLR and ISLR vales of GOA

No. of Pulses	PSLR (dB)	ISLR (dB)
6	-35.05	-26.17
8	-45.55	-23.85
9	-47.70	-32.06
10	-39.82	-22.26

This section presents the optimized PRI sequences of non uniform SFPT signal using Differential Evolution Algorithm and Grasshopper Optimization Algorithm and their respective performance measures. The performance measures PSLR and ISLR of radar signals with the respective optimized non-uniform SFPT PRI sequences are quantified by evaluating their corresponding ambiguity functions. The performance of the algorithms is compared in Table-III.

Table-III: Comparison of SFPT PRI with DE and GOA

Algorithm	No. of pulses	PSLR(dB)	ISLR(dB)
DE	6	-26.65	-17.87
	8	-35.75	-28.81
	9	-42.56	-37.89
	10	-27.57	-19.3
GOA	6	-35.05	-26.17
	8	-45.55	-23.85
	9	-47.7	-32.06
	10	-39.82	-22.26

The simulation results of optimized SFPT signal using Differential Evolution Algorithm and Grasshopper Optimization Algorithm are compared in Table 3. Of all the results, the PSLR of SFPT signal with N=9 optimized using

Grasshopper Optimization Algorithm has shown the better value of -47.70 dB.

IV. CONCLUSIONS

The performance of the radar depends on resolution. Due to the cause of blind speeds the radar resolution is degraded. By changing the PRI blind speeds can be avoided. SFPT is more suitable signal for many radar applications. In this paper, PRI of Non uniform stepped frequency pulse train is optimized for 6, 8, 9, 10 pulses using Differential Evolution Algorithm and Grasshopper Optimization Algorithm. The performance of the algorithms is measured using PSLR. The PSLR obtained for non uniform PRI SFPT using DE algorithm and GOA is -42.56dB and -47.70dB. The Grasshopper optimization algorithm performed better than DE algorithm showing an improvement of -5.14dB. So, it can be inferred that the Grasshopper Optimization Algorithm outperformed Differential Evolution algorithm in optimizing PSLR of Non Uniform PRI SFPT signal.

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