OPTIMIZATION OF NON-UNIFORM PRI COSTAS SIGNAL USING GREY WOLF OPTIMIZER ALGORITHM FOR IMPROVING RANGE RESOLUTION

[1]K. SUJANA, [2]Dr. P. RAJESH KUMAR

[1]M Tech, Radar and Microwave Engineering , Department of ECE, AUCE(A), Andhra University, Visakhapatnam, Andhra Pradesh,

[2]Prof, Department of ECE, AUCE(A), Andhra University, Visakhapatnam, Andhra Pradesh.

Abstract

Pulse compression techniques have been widely used in several modern radar systems. Costas signal also called as Costas array is one of the techniques of pulse compression. Costas signal is used to generate a sequence of frequencies that produces unambiguous range and Doppler measurements within radar while minimizing the crosstalk between frequencies. Generation of non uniform PRI sequences of Costas signals are considered using conventional methods. The performance of the signal measured by two main parameters, Peak Sidelobe Level Ratio (PSLR) and Integrated Sidelobe Level Ratio (ISLR). The PSLR and ISLR are derived from the autocorrelation pattern. Here, evolutionary algorithms used to optimize non-uniform PRI sequence of radar signal (Costas signal) for improving the range resolution. This work will compare two optimization algorithms which are Genetic algorithm and Grey Wolf optimizer algorithm.

Keywords: *Pulse Repetition Interval, PSLR, ISLR, Genetic Algorithm, Grey wolf Algorithm.*

1. INTRODUCTION

RADAR [1] stands for Radio Detection and Ranging System. It is basically an electromagnetic system used to detect the location and distance of an object from the point where the RADAR is placed. It works by radiating energy into space and monitoring the echo or reflected signal from the objects. It operates in the UHF and microwave range. The RADAR system generally consists of a transmitter which produces an electromagnetic signal which is radiated into space by an antenna. When this signal strikes any object, it gets reflected or reradiated in many directions. This reflected or echo signal is received by the radar antenna which delivers it to the receiver, where it is processed to determine the geographical statistics of the object. The range is determined by the calculating the time taken by the signal to travel from the RADAR to the target and back. The target's location is measured in angle, from the direction of maximum amplitude echo signal, the antenna points[2]. To measure range and location of moving objects, Doppler Effect is used.

The radar antenna illuminates the target with a microwave signal, which is then reflected and picked up by a receiving device. The electrical signal picked up by the receiving antenna is called echo or return. The radar signal is generated by a powerful transmitter and received by a highly sensitive receiver[3].

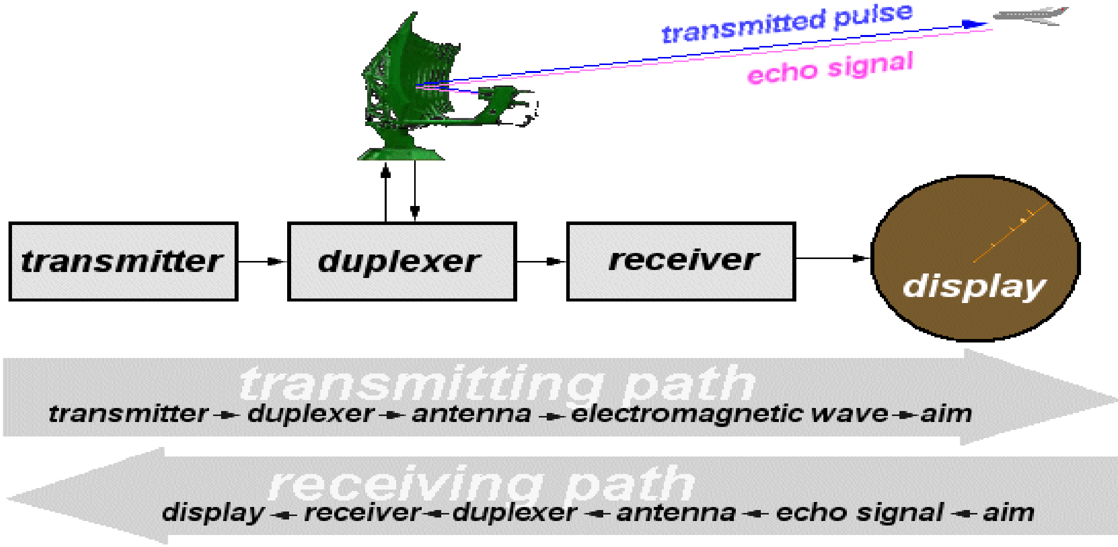

Fig 1. Radar Block Diagram

2. RELATED WORK

Mark W. Maier [4] described Several applications most amenable to the strengths and limitations of non-uniform PRI waveforms. The steady increase in digital signal processing power available has slowly increased the complexity of radar waveforms. Increases in power will allow use of non-uniform PRI in concert with the coherent integration of pulse-Doppler systems. This paper has shown that there are no insurmountable obstacles to such a fusion. Processing requires only sufficient power. Clutter rejection is a more complex problem, but is solvable for specific, high leverage applications.

John P. Costas [5], proposed permutation matrices which are used to determine the frequency- time pattern of a uniform pulse train. When one of the special permutation matrices described, the basic pedestal components are denied location coincidences throughout the sidelobe region. Therefore the peak non-central response minimized. The frequency-channel spacing is the reciprocal of the pulse length, prevents ambiguities along the delay axis. So that the resulting central peak provides good resolution in both delay and frequency.

Solomon W. Golomb [6], described two approaches to identify the Costas arrays. One is exhaustive search and another one is specific construction methods. The author searched other systematic constructions to identify the possibility of pattern recognition. JAMES K. BEARD [7], introduced two new extensions of number-theoretic methods to find two new Costas arrays. Here, as N (order of arrays) increases, the numbers of Costas arrays that are not found by the number-theoretic generators and their generalizations decreases and the probability of their existence declines. Solomon W.Golomb [8], introduced construction and properties of a new Costas arrays by using systematic methods of construction which are Welch construction and Lempel construction and listed the unsolved problems of "honeycomb arrays".

Konstantinos Drakakis [9], importance of Costas arrays in different fields by collecting information on history of subjects, construction methods, construction algorithms with proofs. This theory involves interesting mathematics. The mathematician plays a main role in this paper. Avraham Freedman [10], introduced a staggered Costas signals to obtain favorable ambiguity functions and combined the qualities of both thumbtack and bed of nails signals. The ambiguity function plots of staggered Costas signals gave their importance over other frequency (d) modulated signals, such as linear FM and V-FM, and over phase-coded signals such as CPC.

3. COSTAS ARRAYS

A Costas array can be regarded geometrically as a set of n points, each at the center of a square in an $n \times n$ square tiling such that each row or column contains only one point, and all of the $n(n-1)/2$ displacement vectors between each pair of dots are distinct. This results in an ideal "thumbtack" auto-ambiguity function, making the arrays useful in applications such as sonar and radar. Costas arrays can be regarded as two-dimensional cousins of the one-dimensional Golomb ruler construction, and, as well as being of mathematical interest, have similar applications in experimental design and phased array radar engineering.

Costas arrays [11] arise in sonar and radar applications: both of these devices are used to identify the position and velocity of an object, the target. In order to accomplish this task, they emit pulses at some frequency or frequencies, and they receive the signals that result from the reflection of these pulses on the target. The time difference between emission and reception provides the distance of the target from the device, while the frequency difference between the two, as the Doppler Effect stipulates, gives an indication of the speed of the target.

Imagine that we operate our radar or sonar by emitting pulses sequentially at frequencies $f_{i,}$ i=1,….,n, at times ti, $i = 1,\ldots,n$, assumed from now on to be integers between 1 and n, for some n, and by repeating this pattern periodically in time. This technique of varying the emission frequency through time is known as frequency hopping and it gives us the opportunity to make our device robust to noise.

Let us first describe the operation of a device such as the one just described in a noiseless environment: under the assumption that the target moves at a speed that can be considered to be constant throughout the emission cycle of the n pulses, and much less than the propagation speed of the pulses, all pulses will experience almost the same delay and the same frequency shift, so that the set of received pulses will be identical to the set of transmitted pulses, except that it will be shifted in time and frequency. By calculating then the cross-correlation between the transmitted and the received set of pulses that can determine these shifts, and therefore determine the distance and speed of the target.

4. PARAMETRIC EVALUATION

The performance measures of Pulse Compression techniques are Peak Sidelobe Level Ratio (PSLR), Integrated Sidelobe Level Ratio (ISLR).

Peak Sidelobe Level Ratio

It is the ratio of the maximum of the sidelobe amplitude to mainlobe amplitude

$$PSLR = 20\log_{10}\left[\frac{\max(sidelobe\ \ peak)}{mainlobe\ \text{peak}}\right]$$

Integrated sidelobe Level ratio

It the ratio of the energy of Autocorrelation function of sidelobes to the total energy of the Autocorrelation function of the mainlobe

$$ISLR = 10\log_{10}\left[\frac{Energy\ \text{in sidelobe}}{Energy\ \text{in mainlobe}}\right]$$

5. PROPOSED GREY WOLF ALGORITHM

Grey wolf optimizer algorithm [12] ridicules the ability to perform the operation via hunting mechanism of grey wolf which are in nature. They are normally four types of grey wolves that are associated to perform the operation based on the ability of hunting and are given by alpha, beta, delta and omega. In this algorithm they are three main operations to be performed, the operations are hunting mechanism, prey searching, circle prey, and prey attacking which are to be implemented while performing the optimization with the help of GWO algorithm.

Grey wolf optimizer (GWO) is a population based meta-heuristics algorithm simulates the leadership hierarchy and hunting mechanism of grey wolves. The first level is called alpha(α), second level is called beta(β), the third level is called delta(δ) and the lowest level is called omega(ω). Alpha is considered as the fittest solution and the beta and delta are considered as second and third fittest solutions respectively. In GWO algorithm, the hunting is guided by α, β and δ. The ω solutions follow these three wolves.

The mathematical model of the encircling behavior is presented in the following equations

$$\vec{D} = \left| \vec{C} \cdot \vec{X}_P(t) - \vec{X}(t) \right|$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A} \cdot \vec{D}$$

Where

t is the current iteration,

A and *C* are coefficient vectors,

D is the distance vector between prey and grey wolves.

X_p is the position vector of the prey, and *X* indicates the position vector of a grey wolf.

The vectors A and C are calculated as follows:

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \qquad \vec{C} = 2 \cdot \vec{r}_2$$

The components of *a* linearly decreases from 2 to 0 over the course of iterations and r_1, r_2 are random vectors in [0,1].

$$\vec{D}_\alpha = \left| \vec{C}_1 \cdot \vec{X}_\alpha - \vec{X} \right| \qquad \vec{D}_\beta = \left| \vec{C}_2 \cdot \vec{X}_\beta - \vec{X} \right| \qquad \vec{D}_\delta = \left| \vec{C}_3 \cdot \vec{X}_\delta - \vec{X} \right|$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1 \cdot \left(\vec{D}_\alpha \right) \qquad \vec{X}_2 = \vec{X}_\beta - \vec{A}_2 \cdot \left(\vec{D}_\beta \right) \qquad \vec{X}_3 = \vec{X}_\delta - \vec{A}_3 \cdot \left(\vec{D}_\delta \right)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3}$$

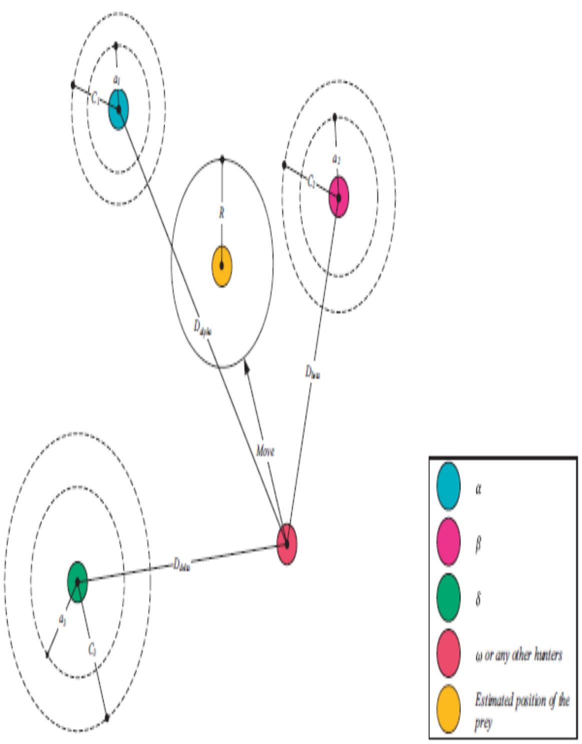

Figure 3. Position updating in GWO

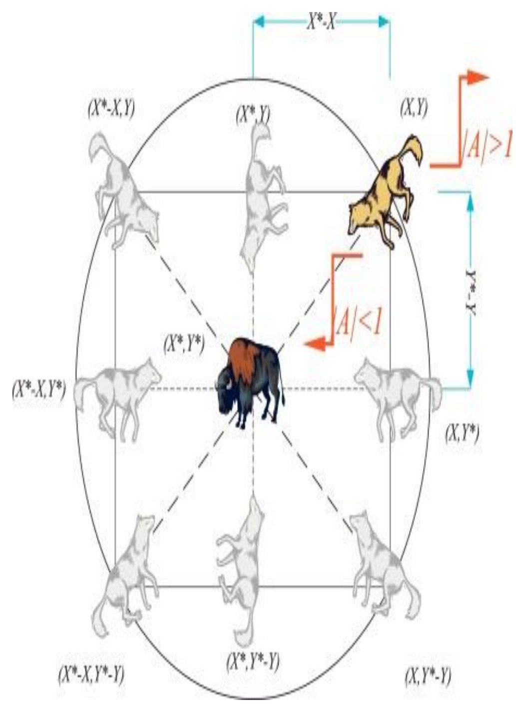

Figure 4. 2D position vector and their possible next location

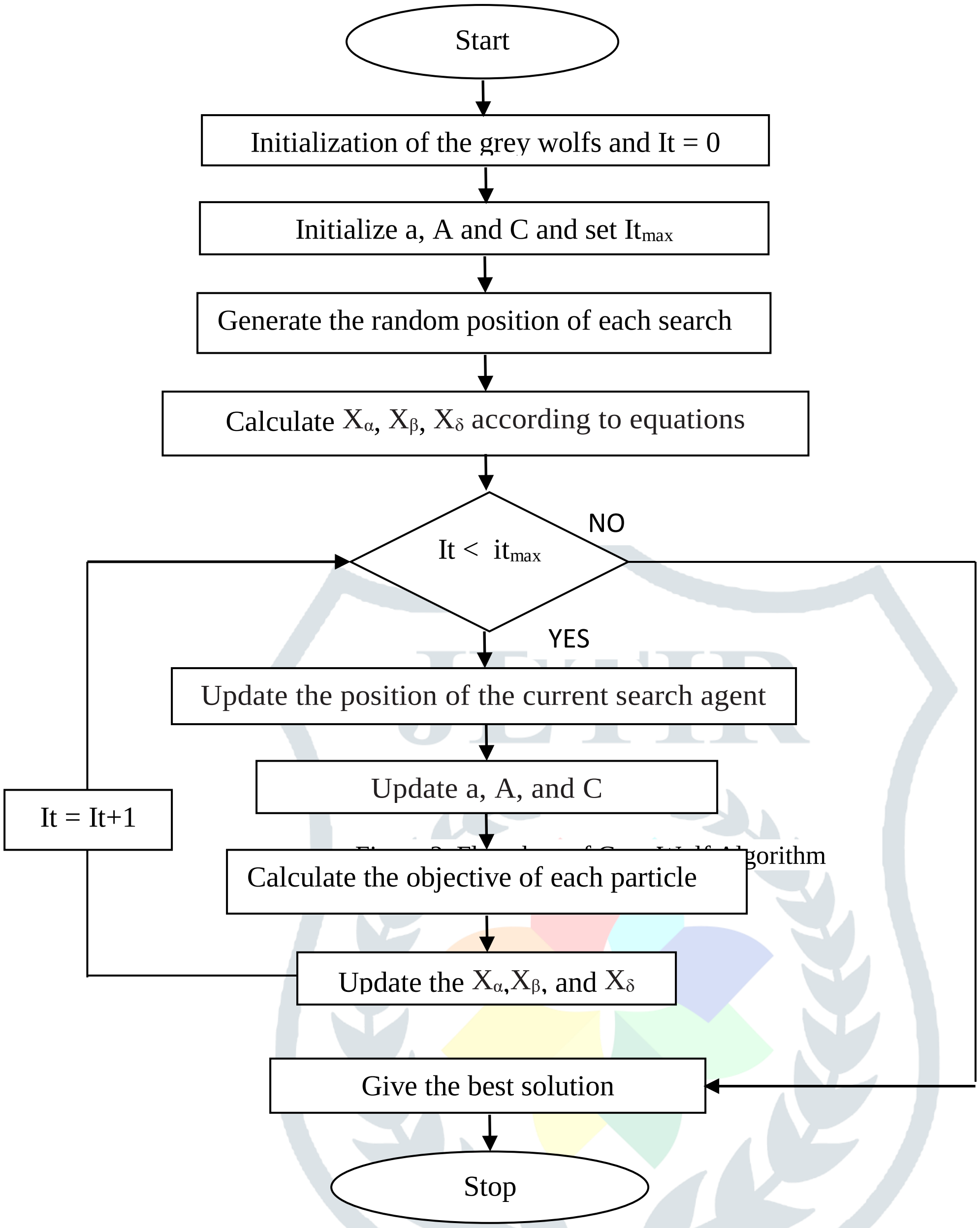

Fig 2. Flowchart of proposed Methodology

5. Results and Discussion

This section presents the uniform, non-uniform increment, decrement, Genetic Algorithm and Grey wolf Optimizer Algorithm optimized Costas PRI sequences and their respective performance measures. Costas pulse trains performance measure plots (ambiguity plot) using GA and GWO are presented and compared for fast convergence. The performance measures PSLR and ISLR of radar signals with the respective optimized Costas non-uniform PRI sequences are quantified by evaluating their corresponding ambiguity functions. The Costas non-uniform PRI sequences of the radar signals are obtained after applying the optimization techniques and their respective performance measures PSLR and ISLR are tabulated below. Hence by Grey Wolf Optimizer Algorithm considerably high values of PSLR and ISLR obtained and range resolution improved.

Ambiguity Plots and PSLR and ISLR values of Costas non-uniform PRI signal with GWO Algorithm

Ambiguity plots obtained by using software MATLAB 2016a. In this considered pulse width is τ =0.4 µs

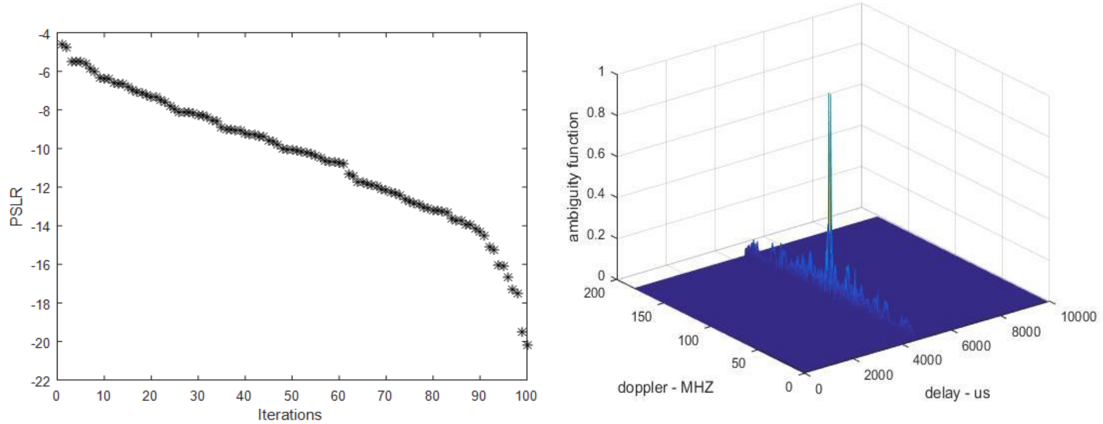

Figure 5. PSLR maximization plot using GWO algorithm for N=6 and Ambiguity plot of Costas non-uniform PRI of 6 length with GWO Algorithm

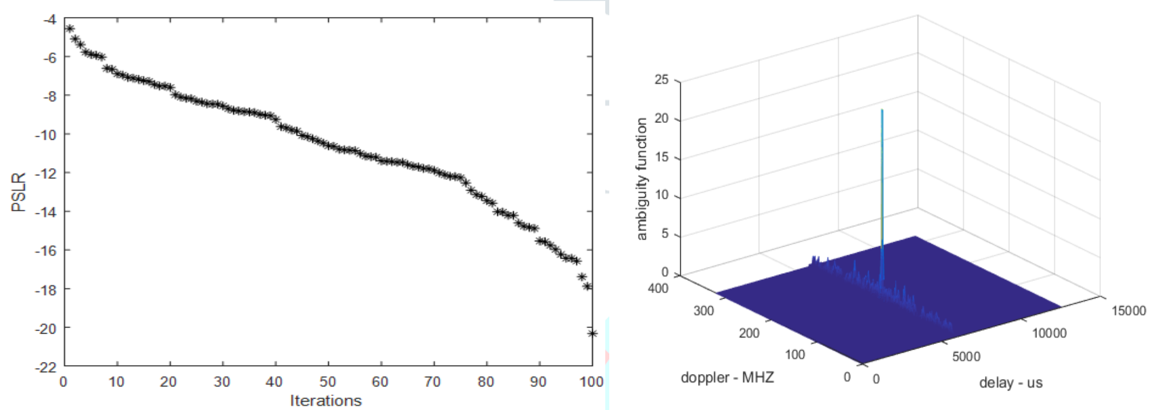

Figure 6. PSLR maximization plot using GWO algorithm for N=8 and Ambiguity plot of Costas non-uniform PRI of 8 length with GWO Algorithm

The figure 5, figure 6 and figure 7 shows ambiguity plots of Costas non-uniform PRI signal with GWO Algorithm of 6, 8 and 9 pulses. The obtained values of PSLR, ISLR for 6 pulses are -19.808 dB and -0.2382 dB respectively. The obtained values of PSLR, ISLR for 8 pulses are -20.535 dB and -1.9816 dB respectively. Similarly for 9 pulses PSLR, ISLR are -21.143 dB and -0.4599 dB respectively.

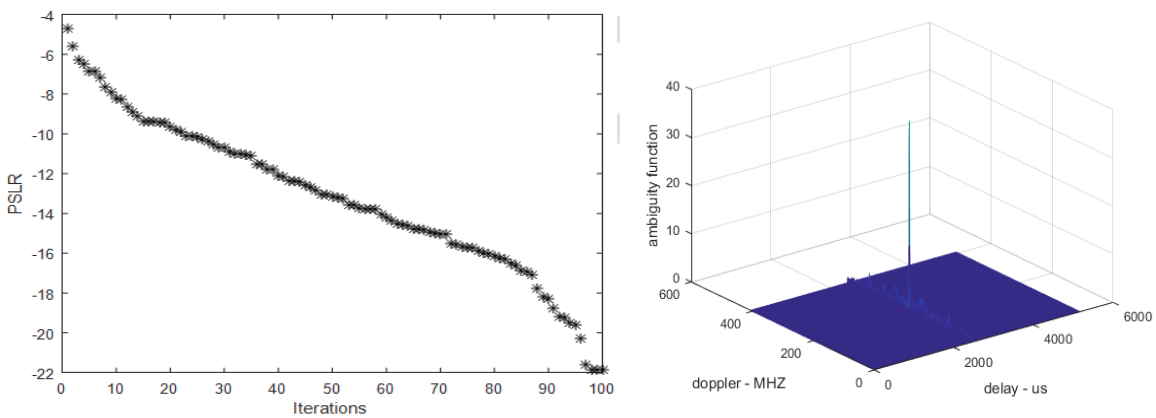

Figure 7. PSLR maximization plot using GWO algorithm for N=9 and Ambiguity plot of Costas non-uniform PRI of 9 length with GWO Algorithm

The table 1 shows the Comparing the PSLR and ISLR values for different cases with lengths of 6, 8 and 9. By comparing with all, the high PSLR and ISLR achieved by GWO Algorithm. The value of high PSLR is -21.143 dB and ISLR value is -1,9816 dB.

Table 1. PSLR AND ISLR values obtained for different Costas PRI signal

No of Pulses	COSTAS PRI Signals	PSLR (dB)	ISLR (dB)
6	Uniform	-1.4124	1.9476
	Non Uniform Increment	-2.423	-0.0338
	Non Uniform Decrement	-2.423	3.1460
	GA	-18.88	1.2382
	GWO	**-19.808**	**-0.2382**
8	Uniform	-2.4201	1.3157
	Non Uniform Increment	-6.5998	3.4673
	Non Uniform Decrement	-6.5998	6.2730
	GA	-18.88	1.2199
	GWO	**-20.535**	**-1.9816**
9	Uniform	-1.5332	1.7680
	Non Uniform Increment	-7.7375	3.3890
	Non Uniform Decrement	-4.782	4.2684
	GA	-18.7543	1.2791
	GWO	**-21.143**	**-0.4599**

5. CONCLUSION

By observing the results, the non-uniform PRI Costas signal given better values of PSLR and ISLR compare to uniform PRI Costas signal. So, the evolutionary algorithms used to optimize non-uniform PRI Costas sequences for improve the performance of Radar signal waveforms. The GWO algorithm achieved better results of PSLR and ISLR compare to GA algorithm. By comparing different number of pulses, the better results of PSLR and ISLR obtained for 9 length Costas non-uniform PRI signal. If PSLR value increases then ISLR value decreases. So, there is a tradeoff between PSLR and ISLR. In future, an advanced Multi-objective optimization algorithms like MOGWO will be used to overcome the tradeoff solutions of both PSLR and ISLR parameters.

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