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Optimal Polyphase Coded Signal Design

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Abstract*: In the war prone global arena where every target of an enemy, on and off the land to be kept on eagle's eye watch and to deceive enemy's counter measure technologies, there is a strong requirement for most secured signal design which domicile maximum detection range along with high range resolution, to flare them up .The efficiency of the system mainly depends on how much power the generated pulse may possess in the main lobe to that of the side lobes and how independent they are from one another. The measure of Autocorrelation and cross correlation exhibited by polyphase coded sequence is determined mathematically. Multi input and multi output possesses best potential in mitigating the effects of fading, enhancing the resolution, suppressing the signal jamming and interference, which are all very useful in improving the target detection and recognition performance of the system. Recently, most optimization researches of polyphase codes are carried out by genetic algorithm (GA), Particle swarm optimization (PSO) and simulated annealing (SA) but this technique require more parameters for optimization. In order to overcome these difficulties modified PSO algorithm is adopted in the present research to optimize the polyphase coded sequence. The obtained codes are also put for Doppler resilience by including Doppler shift in the process of generation of the codes.

Keywords* : Multi Input and Multi Output (MIMO), Modified Particle Swarm Optimization Algorithm (MPSOA), Cross-Correlation Peaks(CPs),Auto-Correlation Peaks (ASPs),Genetic Algorithm(GA),Simulated Annealing Algorithm(SAA).

I. INTRODUCTION

In [1,2] radar object tracking, fading becomes predicament, in the detection of the signal at the reception. In order to overcome the difficulty, attention of the research was focused to multi input and multi output concept, where in which, number of transmitters and receivers are employed to detect the object with better accuracy[3,4]. In the meantime because of multiple transmission and reception, interference and detection capability of the system has to be taken care of. So in order to possess maximum detection capability and reduce interference between the co-located stations, there is a strong need to have low cross correlation between the adjacent transmitting pulses.

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Range resolution of the radar system increases as the length of sequence increases [5,6] and in turn to procure more security to the sequence, incorporating multiple phases in the sequence is one of the adoptable solutions [7,8]. As a whole the sequence generation becomes more complex in order to

meet all these criteria's. To address these problems there is obviously only one way that can be used for salvation is optimization of sequences [9,4]. In this paper we have conducted a trail to find a meaningful solution to address all the complexities arising in multi input and multi output radar object tracking, by optimizing the poly phase codes with higher probability of detection.

Deng, H et al., [10] The statistically evaluated SA algorithm is integrated with traditional iterative code selection technique for polyphase code optimization to offer efficient results in Orthogonal netted radar systems (ONRS). The frank sequence exhibited by the system seems to be better when compared to the autocorrelation property with respect to random signals and arbitrary code length. Refining certain parameters like high initial temperature and slow cooling system results in producing improved results eventually at long run time Hai Deng et al., [11] presented a novel hybrid algorithm based on SA algorithm and demonstrated the polyphase signals in ONRS. By fine tuning the parameters better results has been achieved by significant computational time increase. After the development of simulated annealing and discrete frequency coding waveform (DFCW).Hai Deng et al., [12] stated that the basic simulated annealing algorithm performs less effective for more orthogonal waveform. Then, proposed an enhanced simulated annealing algorithm which performs effectively. Doppler shift tolerant design is based on the design cost function. By using this algorithm very effective result has been achieved through Doppler tolerant waveform.

Xiangneng Zeng et al., [13] stated that polyphase coded signal with good orthogonal properties has optimization problem. GA and PSO pretends to be an excellent alternative to overcome this drawback. Therefore, an innovative MPSO method is proposed which solves the optimized problem with high dimension and gave efficient performance result. Roja et al. [14] employed an accelerated continuous PSO for designing discrete frequency coded waveform in which better correlation properties in terms of Peak side lobe level ratio and integrated side lobe level ratio is obtained. Jingjun Li et al., [15] improvised the discrete particle swarm optimization algorithm and used in orthogonal discrete frequency coding waveforms which are used to generate the sequences. This new algorithm gives better design result than the simulated annealing algorithm. Milad Malekzadeh et al., [16] demonstrated two algorithms named as Artificial Bee Colony (ABC) and Bee Algorithm (BA) to design orthogonal polyphase code [19].

These algorithms tried to diagnose the problems. Each algorithm plays a different attractive ability to design peak side lobe of cross correlation (CPs), Auto correlation (ASPs) for tracking the object in space through MIMO radars from different angles. Here, For CPs design, Bee Algorithm plays better role than Artificial Bee Colony. For ASPs, Artificial Bee Colony plays better role than Bee algorithm.

Reddy, B et al., [17] modified ant colony optimization algorithm optimizes DFCW sequences with better results than that of other GA, SA algorithm regarding computational time and it can also handle larger N values. Hamming scan algorithm is also utilized to perform neighborhood search point, thus minimizing the cost function. Reddy, B et al., [18] Polyphase Coded sequence possessing better cross correlation and aperiodic autocorrelation are designed by Modified PSO which results in less computational complexity. Further it can also be optimized using a Hamming scan algorithm. Thus, improved performance with better correlation properties are observed when compared to PSO and GA algorithm.

Samir et.al proposed multifunction antenna system composed of horn antenna with feeding slotted wave guide which functions simultaneously for both radar and communication applications. The radiation from horn antenna is utilized to operate radar and with a provision of plain switching mechanism for each radiating slot, radiation can be controlled independently and is used to carry binary phase shift keying (BPSK) communication. The measured results for the proposed technique offer two varied function by means of orthogonal polarization and directions showing isolation loss of 9.1 dB and 32 dB respectively among them at its working frequency.

Inorder to utilize frequency response effectively and to gather multi-static information, lee and Kim adopts a radar network with shorter wavelength configurations which constitutes higher resolution Ka-band pulse compressive radars [22]. Field programmable gate array (FPGA) and direct digital synthesizer (DDS) generates linear as well as arbitrary nonlinear modulated frequency waveform for low ranged side-lobes. Setting up in vertical-point mode, moderate rainfall approximately close to 15 km is detected.

II. FORMUATION AND RESULTS

A. Polyphase Codes

The phase of the polyphase code (M phase code) selects M arbitrary sub pulse value. Polyphase code uses harmonic phases at several phase increment. Polyphase code phase is less than radians and is able to provide better correlation characteristics and wider design options than the binary codes. The ratio of wide lobe to side lobe is wider when compared to binary signal of similar length code. Likewise, the range side lobes of polyphase code waveform are lesser than the binary code waveform of equal length. The phase equation for polyphase code is given with Eqs.(1) as..

$$s_l(n) = e^{j\phi_l(n)} \tag{1}$$

In which $\phi_{l(n)}$ dictates the phase enabled by n bit signal that takes arbitrary value between 0 and 2π in signal set, where l=1, 2, …., L and n=1, 2, …., N. The range of $\phi_{l(n)}$ is given in Eqs.(2).

$$\phi_l(n) \in \left\{0, \frac{2\pi}{M}, 2.\frac{2\pi}{M}, ..., (M-1).\frac{2\pi}{M}\right\} \tag{2}$$

Consider a code set S, possessing L set size, N code and distinct M phase number. The phase value of code set is represented by the matrix given in Eqs. (3).

$$S(L,N,M) = \begin{bmatrix} \phi_1(1) & \phi_2(1) & \dots & \phi_1(N) \\ \phi_2(1) & \phi_2(1) & \dots & \phi_2(N) \\ \vdots & \vdots & & \vdots \\ \phi_L(1) & \phi_L(2) & \dots & \phi_L(N) \end{bmatrix} \tag{3}$$

The autocorrelation and cross correlation function exhibited by the code sequence is illustrated in (4) and (5) respectively

$$A(\phi_1, K) = \begin{cases} \frac{1}{N}\sum_{n=1}^{N-1} \exp j[\phi_1(n) - \phi_1(n+k)] = 0 & 0 < k < N \\ \frac{1}{N}\sum_{n=-k+1}^{N-1} \exp j[\phi_1(n) - \phi_1(n+k)] = 0 & -N < k < 0 \end{cases} \tag{4}$$

Where l=1, 2, …. L.

$$C(\phi_1, k) \approx \begin{cases} \frac{1}{N}\sum_{n=1}^{N-k} \exp j[\phi_q(n) - \phi_p(n+k)] = 0 & 0 < k < N \\ \frac{1}{N}\sum_{n=-k+1}^{N-1} \exp j[\phi_q(n) - \phi_q(n+k)] = 0 & -N < k < 0 \end{cases} \tag{5}$$

The above relation is valid when p≠q and p, q=1, 2,….L. Cost function is defined as summation of squared value of autocorrelation and cross correlation parameter and are dictated as

$$E = \sum_{I=1}^{L}\sum_{I=1}^{L} |A(\phi_1, K)|^2 + \lambda \sum_{P=1}^{L}\sum_{q=p+1}^{L}\sum_{K=-(N-1)}^{N-1} |c(\phi_P, \phi_q, k)|^2 \tag{6}$$

λ denotes the weightage parameter. Greater value of λ i.e λ>1 prefer cross correlation peak value by giving more weighting than that of the autocorrelation peaks.

B. Modified Particle Swarm Optimization Algorithm (MPSO)

Though the polyphase sequences have number of advantages, the main problems with such sequences occur in accurate generation and maintenance of bulk quantity of phases.

The increase in number of phases (M), leads to linear increase in the number of searches, i.e. MN, in where N represents the sequence length. The first problem can be solved by using high speed and low-cost modern DSP processors, which are readily available in the market, and the second problem can be solved through globally optimized SA, Taboo search algorithm (TSA) and GA techniques etc.

The present work defines a modified PSO method to design polyphase orthogonal sequence sets, which has a significant role in radar system to improve its performance.PSO algorithm is slightly modified in order to optimize the polyphase codes such that the convergence rate and population size can be reduced. Certain advanced versions of PSO involves variations in fundametal factors like learning factors, speed, inertia mass and swarm size and it is found out that PSO is sensitive for these factors. Velocity plays a main function in PSO , where it is subjected to dynamic adjustment based on historical behavior of the particles and their companions. On the contrary, MPSO comprises new velocity vector with respect to the maximum distance between any two locations in the solution area. Eqs. (8) relates the velocity update, where the personal best position influences the new position of the particle. The ith particles position and velocity for the d dimensional search space is Xi and Vi respectively. The particles maintain storage of their previous best position P_i.

For every iterations, pbest represents the vector particles p with best fitness particularly in local neighborhood search space. The particles new position is determined using the velocity.In this algorithm for a fixed threshold value T, in case the uniformly distributed random number U(0, 1) is lower than T, Eqs. (8) generates the velocity vector, else Eqs. (7) generates the velocity vector.

$$V_{id}^{t+1} = wV_{id}^{t} + c_1 r_1 (P_{id}^{t} - x_{id}^{t}) + c_2 r_2 (P_{id}^{t} - x_{id}^{t}) \quad (7)$$

The above relation represents the relation existing among inertia weight, the velocity, position vector, local best and global best of i particle in dimension d at time t. c1 and c2 are Learning factors.

$$V_{id}^{t+1} = w\beta d (P_{gd}^{t} - P_{id}^{t}) \quad (8)$$

where w is an Inertia weight, d illustrates the Maximum Distance and Fraction of Objective Function Value. The distance between global and personal best particles is given by

$$d = \frac{d_{\max} - d_{gi}}{d_{\max}} \quad (9)$$

Where d represents the maximum distance existing among the two different point in search space and is given by the distance between the global best particle and the ith particle. Its maximum distance at (x, y) is computed as

$$d_{\max} = \sqrt{\sum_{i=1}^{D} (y_i - x_i)^2} \quad (10)$$

The distance between the global best particles xp and ith particle xq can be calculated as

$$d_{pq} = \sqrt{\sum_{I-1}^{D} (x_{pi} - x_{qi})^2} \quad (11)$$

Where D represents the dimension of swarm . Fraction of objective function values of global best and current particles are given as

$$\beta = \frac{f(p_g)}{f(x_i)} \quad (12)$$

where and are the fitness value of the global best particle and ith particle . By dynamically adjusting the velocity, the inertia weight has to control exploration and exploitation of the search space. A large and small inertia weights facilitate global and local explorations respectively. A properly chosen inertia weight makes both the explorations of the swarm balanced and it leads to a better solution. Setting the inertia weight to a larger value results in effective global exploration, and that is decreased to obtain more refine solution. Inertia weight involves a linear variation from 0.9 to 0.4. While varying the threshold (T) for several values, 0.65 is found to be the best value.

III. RESULTS

The peak side lobe of autocorrelation and cross correlation function of MPSO and PSO is presented in table 1.

Table 1. Autocorrelation and cross correlation of polyphase sequence set with M=4, L=3 ,N= 40, and λ =0.9.

PSO	Seq 1	Seq 2	Seq 3
Seq 1	-23.09dB	-20.81dB	-20.63dB
Seq 2	-20.81dB	-22.97dB	-20.81dB
Seq 3	-20.63dB	-20.81dB	-22.97dB

Modified PSO	Seq 1	Seq 2	Seq 3
Seq 1	-25.84	-22.15	-22.04
Seq 2	-22.15	-26.02	-22.27
Seq 3	-22.04	-22.27	-25.67

The diagonal term represents the normalized ASPs whereas the other term indicates the normalized CPs values. Seq is the sequence of the of the pulse compression radar. The values are computed for three different sequence sets. For PSO, the average value of ASPs and CPs is indicated as -23.01dB and -20.75dB but in the case of MPSO, it is pointed as -25.84dB and -22.15dB. Thus, the results predict that the MPSO provide lower values with the decrement in the ASPs and CPs values by 2.83dB and 1.29dB.

Table 2. Autocorrelation and cross correlation of designed poly phase sequence Set with M=4, L=3, N= 128 and =0.9.

PSO	Seq 1	Seq 2	Seq 3
Seq 1	-27.53	-26.02	-25.67
Seq 2	-26.02	-27.53	-26.37
Seq 3	-25.67	-26.37	-26.93
Modified PSO	Seq 1	Seq 2	Seq 3
Seq 1	-29.62	-27.53	-27.13
Seq 2	-27.53	-29.11	-26.93
Seq 3	-27.13	-26.93	-29.89

Constant parameters values offer significant variations between different sequence sets. The normalized ASPs values are specified in diagonal terms and the normalized CPs values are given as off diagonal terms. From the Table 2 the average value of ASPs and CPs for PSO is revealed as -27.33dB and -26.02Db. But MPSO decrements the ASPs values by 2.21dB and CPs value by 1.17dB and produces -29.54dB and -27.19dB. Overall, it can be said that MPSO possess improved results when compared to other existing method.
Setting the values of L=3, M=4 and N=128 as constant, the correlation value of MPSO is determined. The variation of doppler loss with respect to doppler frequency is plotted.

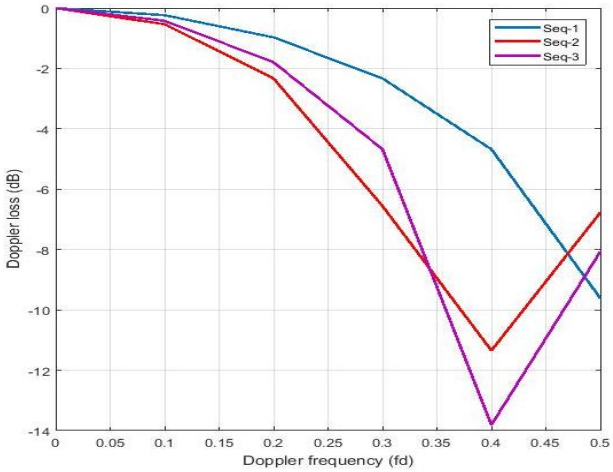

Fig 1. Doppler variation of polyphase sequences with (L=3, M=4 and N=128).

Fig. 1 shows Doppler tolerance for a MPSO sequence of length 128. Deng et al. [11] shows a higher deterioration in polyphase sequence with increased Doppler frequency 0.35, at Doppler loss of 12 dB. MPSO produces 9.25dB Doppler loss exactly at identical Doppler frequency. MPSO fails to deviate similar to PSO a small dip establishes at Doppler frequency of 0.4 and then rises again.

Table 3. Autocorrelation and cross correlation of the designed polyphase sequence Set with M=4, L=4, N= 40 and λ =0.9.

Proposed Technique	Seq 1	Seq 2	Seq 3	Seq 4
Seq 1	0.046	0.054	0.051	0.054
Seq 2	0.054	0.065	0.054	0.054
Seq 3	0.051	0.054	0.031	0.054
Seq 4	0.054	0.059	0.054	0.051

Existing Method	Seq 1	Seq 2	Seq 3	Seq 4
Seq 1	0.111	0.200	0.201	0.201
Seq 2	0.201	0.090	0.212	0.182
Seq 3	0.201	0.212	0.125	0.213
Seq 4	0.201	0.182	0.213	0.226

Thus, polyphase sequence are designed using MPSO at varied length but its correlation property with sequence length 40 and 128 are only used to compare with existing technique [21]. Table 3 presents the four different polyphase sequences with arbitrary length 40 with mean auto correlation and cross-correlation of -26.37dB, and -25.35dB, thus providing an efficient polyphase sequence at identical length [20].

IV. CONCLUSION

In this research, a novel and potential optimal poly phase code set is designed using modified PSO. The main contributions of this research are to develop an efficient global optimization technique for designing optimal polyphase sequences with lower autocorrelation and cross-correlation peak side lobe. The proposed MPSO produces a decrement of 5.94 % in the average autocorrelation sidelobe peaks and 8.2 % decrement in cross-correlation peaks, when compared with PSO technique. Compared with existing method the proposed modified particle swarm optimization algorithm achieves a Doppler tolerance of 2.75dB.

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