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Hybrid Particle Swarm Optimization for Generation of Sequences with Good Correlation Properties

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Abstract

Radar applications require waveform sequences with maximum autocorrelation and minimum cross correlation. Attaining such waveform sequences is a complex multivariable problem. So the tricky of waveform design stated above is a thought-provoking problem. Several global optimization algorithms like ant-colony algorithm, tunneling algorithm, genetic algorithm, bat algorithm, were stated in the literature for solving the problem of waveform design. The paper targets at the design of optimal set of Binary Sequences using hybrid Particle Swarm Optimization Algorithm which makes use of Hamming Scan Algorithm for Mutation. The main advantage of HSA Algorithm is it enhances the search space of PSO, thereby preventing the local optimum trapping of PSO. The synthesized Binary Sequences using Hybrid PSO have improved autocorrelation properties than standard PSO.

Keywords—Auto-Correlation, Optimization, Modified Particle Swarm Optimization (MPSO), Discrimination Factor (D), Hamming Scan Algorithm (HSA).

1. Introduction

Pulse compression is a method of breaking the unwanted constraint between range and resolution [6]. Pulse compression radar transmits a frequency or phase modulated pulse, which is both long (having good range characteristics) and wideband (having good range resolution criterion). The received echo signal is processed in a matched filter that compresses long pulse to a narrow pulse that distinguishes narrowly spaced targets. However, this separation is achieved at the cost of sidelobes, which hide weak targets. As a result, in radar application domains the pulse compression sequences having high discrimination factor are required to achieve high range resolution. Range resolution is the ability of the radar receiver to identify closely spaced targets. The term Discrimination (D) is defined as the ratio of main peak in the auto-correlation to absolute maximum amplitude amongst side lobes [3]. In this framework, Barker [4] has presented binary sequences with side lobe levels either unity or zero. The discrimination of the Barker codes is equal to the length of the code. But, so far the Barker sequences for lengths greater than 13 are not found. In view of the above fact, the discrimination is considered as the figure of merit of the code, for which many researchers have started working with diverse ways of design of binary sequences with discrimination superior than 13.

2. Binary Phase Codes

A sequence has optimum enactment, if it has maximum main lobe energy for zero shifts and zero side lobe energy for other shifts. Merit factor, Discrimination factor, Energy efficiency and Quality factor are different criteria for evaluating goodness of pulse compression sequences .

Let S = [r0, r1, r2, r3 ……….rL-1] be a real sequence of length *L*, with values of 1 and -1.

$$\text{Let} \quad x(k) = \sum_{i=0}^{l-1-k} r_i r_{i+k} \qquad (1)$$

Where k = 0, 1, 2… *L* -1 is its aperiodic autocorrelation.

The fraction of the amplitude of main peak in the autocorrelation to the absolute maximum amplitude among side lobes is referred as The Discrimination Factor [9].

$$DF = \frac{x(0)}{Max_{k\neq 0}\,|x(k)|} \qquad (2)$$

To evaluate weather a designed signal is Good or Poor Discrimination Factor is used. This gives that a coded signal with more discrimination factor is a good code while a code with small discrimination factor is poor code. The discrimination factor describes how the main lobe of a coded signal is different form the peak side lobe level. Hence it indicates the amount of goodness of the given coded signal.

3. PSO Algorithm

The PSO algorithm is a novel stochastic search algorithm based on population and is an another solution to the complex non-linear optimization problem. This algorithm is capable of optimizing a non-linear and multidimensional problem which usually reaches good solutions efficiently while requiring minimal parameterization. Dr. Kennedy and Dr. Eberhart were the scientists who had introduced the PSO algorithm first in 1995 and its idea came from simulation of the social behavior of animals [1]. These roots in natural processes of swarms lead to the categorization of the algorithm as one of Swarm Intelligence and Artificial Life. It is established on the usual process of cluster communication where a group of birds or insects share individual knowledge when searching food or migrate and so forth in a search space, even though all birds or insects do not have any idea where the best position is. However, if any associate can find out a appropriate path to go, the rest of the members will follow quickly, based on the nature of the social behavior. Investigators shown that although PSO finds solutions greatly quicker than most of the present-day search techniques like Evolutionary and Genetic Algorithm, it generally do not increase the quality of solutions as the number of reiterations rise and thus becomes a victim of early convergence causing in a suboptimal solution. Lack of diversity is the drawback of PSO which forces the swarm particles to converge to the local optimum.

4. Hamming Scan Algorithm

One of the ways for maintaining the diversity of the population is inclusion of the concept of mutation. The mutation is a word symbolically used for a alteration in an element in the coded sequence. In the present work we have used HSA for mutation. HSA searches in the neighbourhood of the point in all directions. With HSA, every element of the coded sequence is mutated with all other possible elements in the sequence. For example the code element 1 of sequence X is mutated by -1, and cost for the mutated element is calculated. The new element is accepted after mutation if the cost is decreased else the original element is reserved. This procedure is applied to every element in the sequence recursively. Therefore, HSA implements search among all the Hamming-1 neighbours of the sequence and select the one whose cost function value is minimum.

5. Working of HPSO Algorithm

In HPSO, every particle preserves best solution (fitness) that has attained so far by that particle which is connected with the its coordinates in the solution space. This solution is referred to as personal best, **Pbest**. The other best value that is tracked by the PSO is the best value attained so far by any particle in the vicinity of that particle. This solution is called global best (**Gbest)**. In this algorithm we have a completely connected swarm, meaning that all the particles share information, any particle knows what is the best position ever visited by any particle in the swarm.

The major phases of HPSO algorithm for the design of binary sequences is given below

1. Generate particles and initialize with random velocity and position.

2. Evaluate every particle's cost (E), which is the fraction of amplitude of main peak of the auto

correlation to the absolute maximum amplitude among the side lobes.

3. For every particle, if the cost (*E*) is less than its earlier fitness Pbest (personal best), then update the personal best (Pbest).

4. For every particle, if the cost (*E*) is less than the best one of all the particles (Gbest), then update the global best (Gbest).

5. For every particle

a) Generate a new particle using the following equations

$$S_j[t+1] = \mu S_j[t] + K_1 * rand() * (Pbest_j[t] - P_j[t]) + K_2 * rand() * (Gbest_j[t] - P_j[t]) \quad (3)$$

$$P_i[t+1] = P_i[t] + V_i[t+1] \quad (4)$$

where $S_i[t]$ and $S_i[t+1]$ are the earlier and the present velocity of the j^{th} particle. Here $P_j[t]$ denotes the position of the j^{th} particle. Here μ is an inertia weight which defines how far the earlier velocity is preserved (selected $\mu = 0.99$). This indicates that the previous velocity is preserved almost but not preserved completely to avoid absconding from the optimum value. K_1 and K_2 are the accelerating constants which are assigned a random value selected from 0 to 1 in an uniform distribution. The function rand() selects a value between 0 and 1.

b) Mutating the elements in P with HAS to generate a new particle P^1.

c) Compare P and P^1 to pick the one with low cost value.

6. If the stop criterion is met, then stop, otherwise go to Step 3.

6. **Implementation of HPSO Algorithm**

Binary codes having good auto-correlation properties are synthesized by using Particle swarm optimization algorithm through a MATLAB program. A MATLAB program is designed to perform autocorrelation on each sequence. The output of the autocorrelation function gives peak lobe and side lobes. The sequence in which the peak sidelobe level minimum is taken as the best sequence. The simulation was done using MATLAB R2019a. The implementation report for binary sequence of length 20 is given below. Fig.1 shows the simulation waveforms for above sequences. From Fig.1 it can be perceived that the binary sequence 10001101010011011111 1 (1-1-1-1 1 1-1 1-1 1-1-1 1 1-1 1 1 1 1 1) has minimum side lobe amplitude and it is 2. Hence, the discrimination factor of this sequence is 10.

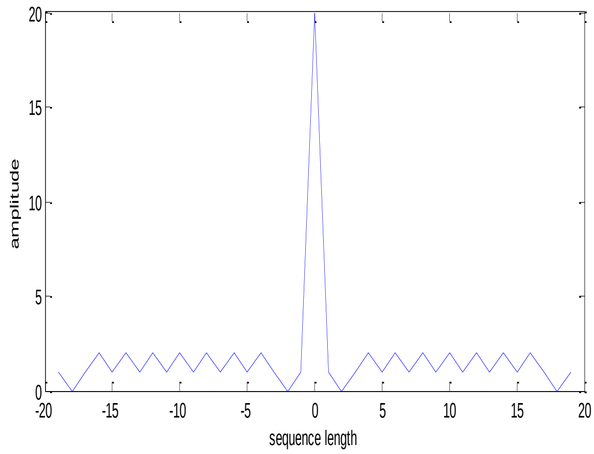

Fig.1: Matlab result for 20-bit Binary Phase Sequence using MPSO.

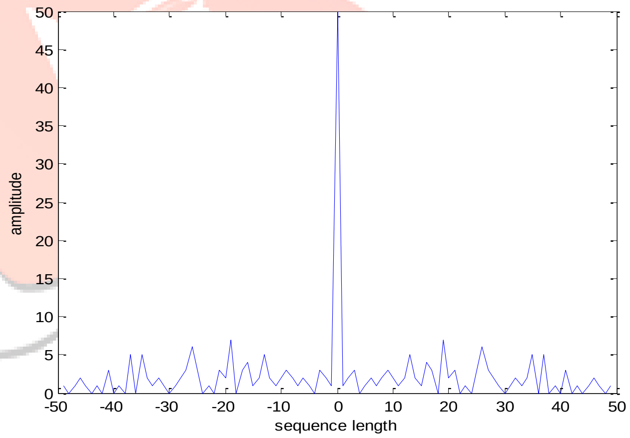

Fig.2: Matlab result for 50-bit Binary Phase Sequence using PSO.

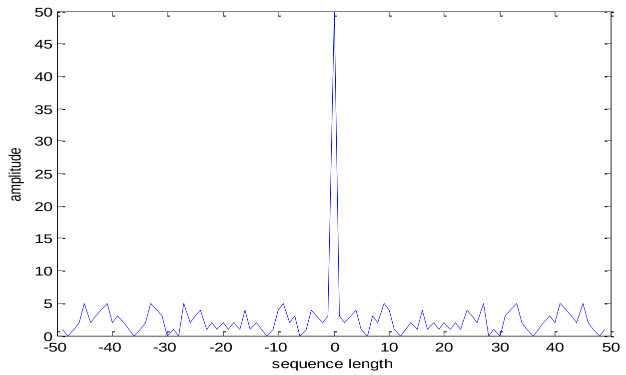

Fig.3: Matlab result for 50-bit Binary Phase Sequence using HPSO.

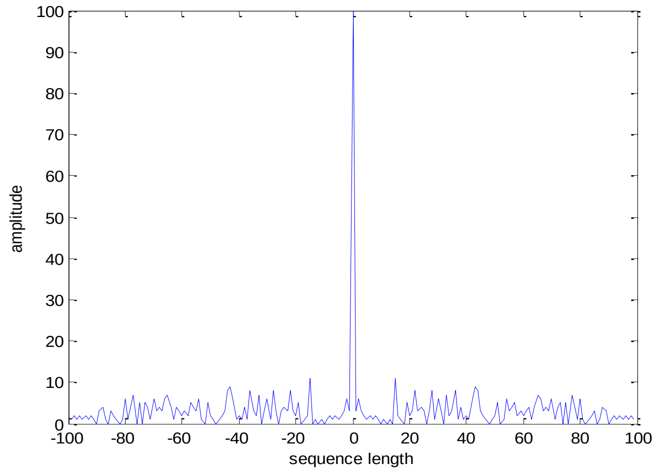

Fig.4: Matlab result for 100-bit Binary Phase Sequence using PSO.

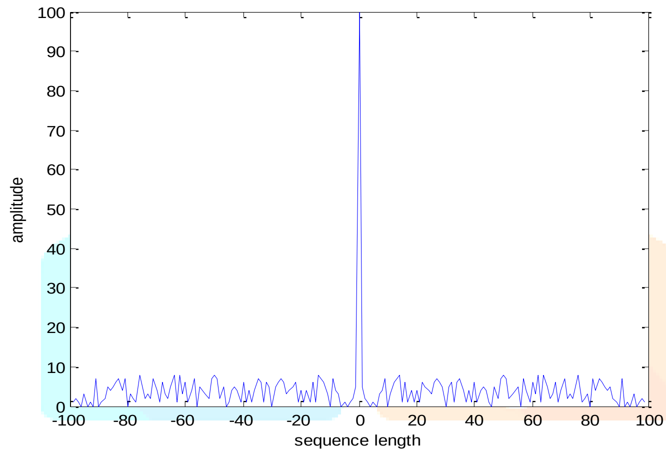

Fig.5: Matlab result for 100-bit Binary Phase Sequence using HPSO.

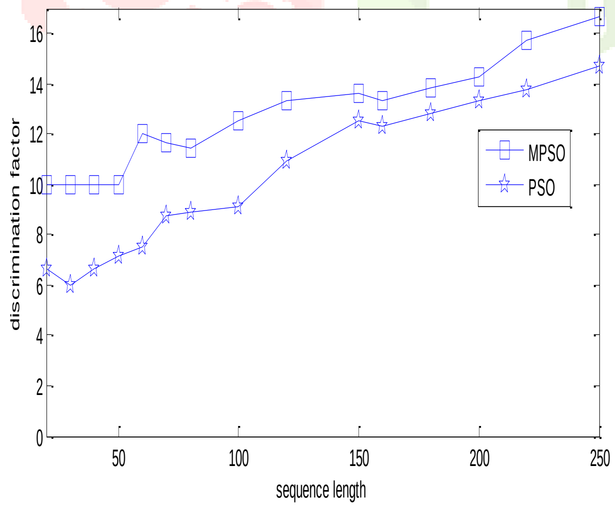

Fig. 6: Matlab result for 13-bit Binary Phase Sequence using HPSO.

Sequence Length	Standard PSO		HPSO	
	Max ASP	DF	Max ASP	DF
20	3	6.67	2	10
30	5	6	3	10
40	6	6.67	4	10
50	7	7.14	5	10
60	8	7.5	5	12
70	8	8.75	6	11.67
80	9	8.89	7	11.43
100	11	9.09	8	12.5
120	11	10.9	9	13.34
150	12	12.5	11	13.63
160	13	12.3	12	13.34
180	14	12.85	13	13.85
200	15	13.33	14	14.29
220	16	13.75	14	15.71
250	17	14.7	15	16.7

Table.1: Discriminator Factor (DF) and Maximum Autocorrelation Sidelobe Peakes (ASP) for Synthesized Binary Sequences with PSO and HPSO.

7. CONCLUSION

The binary coded sequences are generated using the proposed Hybrid PSO algorithm. The generated sequences have better correlation properties than the standard PSO. These sequences are widely used for improving system performances such as radar and spread spectrum communications. The results of the proposed Hybrid PSO algorithm are presented in Table.1, which outperforms the standard PSO. In PSO, there is no selection operation like in genetic algorithms, which improves the speed and decreases trickyness of the algorithm. Main drawback of the genetic algorithm is as the sequences length increases, it takes more time to converge. Therefore global optimization algorithms like Particle Swam algorithms are used for the generation of coded sequences with good autocorrelation and cross-correlation properties.

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