Generation of Sequences with Good Correlation Properties Using Modified Bat Algorithm

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Abstract: Radar applications require sequences with individually peaky autocorrelation. It is a combinatorial problem to obtaining such sequences. So designing a signal above referred is a challenging problem for which many global optimization algorithms like genetic algorithm, particle swarm optimization algorithm, simulated annealing, tunnelling algorithm were reported in the literature. The paper aims at the design of optimal set of Binary Sequences using Modified Bat Algorithm which makes use of Hamming Scan Algorithm for Mutation. The main advantage of Bat algorithm with HSA Algorithm is it enhances the search space of MBA, thereby preventing the local optimum trapping of MBA. The synthesized Binary Sequences using Modified Bat algorithm have better autocorrelation properties than Bat algorithm.

Keywords—*Auto-Correlation Sidelobe Peaks (ASP), Bat Algorithm (BA), Optimization, Modified Bat Algorithm (MBA), Discrimination Factor (DF), Hamming Scan Algorithm (HSA).*

I. INTRODUCTION

Pulse compression is a method of breaking the unwanted constraint between resolution and range [4]. Pulse compression radar transmits a phase or frequency modulated pulse, which have both long (having good range characteristics) and wideband (having good range resolution criterion). The received echo signal is allowed to be processed in a matched filter that becomes a short pulse by compressing the long pulse which separates targets which are very close. However, it hides weak targets as separation is achieved at the cost of sidelobes. Therefore, in radar applications high discrimination factor of the pulse compression sequences are desired to achieve high range resolution. Range resolution is the ability of identifying closely spaced targets by radar receiver. The term Discrimination (D) is defined as the ratio of main peak in the auto-correlation to absolute maximum amplitude among side lobes, Moharir [2]. In this context, Barker [3] proposed binary sequences with sidelobe levels either unity or zero. In Barker codes the discrimination is equal to the length of the code. Unfortunately, lengths greater than 13 have not been found in Barker sequences. In fact the discrimination is the figure of merit of the code; many researchers have started working to design binary sequences with discrimination greater than 13.

II. BINARY PHASE CODES

If the sequence gets peaky main lobe energy for zero shifts and zero sidelobe energy for other shifts then the performance of a sequence is optimal. Different methods such as Merit factor, Discrimination factor, Energy efficiency and Quality factor are used to evaluate the goodness of pulse compression sequences. Let S = [x0, x1, x2, x3 ……..xN-1] be a real sequence of length *N*, with values of 1 and -1.

$$r(k) = \sum_{i=0}^{n-1-k} x_i x_{i+k} \quad (1)$$

Where k=0, 1, 2… *N* -1 is its aperiodic autocorrelation. The Discrimination factor is defined as the ratio of amplitude of main peak of the auto correlation to the absolute maximum amplitude in the side lobes [7].

$$\text{DF} = \frac{r(0)}{Max_{k\neq 0}|r(k)|} \quad (2)$$

Discrimination is used to know whether a coded signal is good or poor. This means that a code with low discrimination is a poor code while a code with high discrimination is good code. DF is used as cost function in the paper. To measure how the main lobe signal is different from the peak side lobe level, discrimination is used and it gives the measure of goodness of the given coded waveform.

III. BAT ALGORITHM

From several decades optimization has been an active area of research because many real-world optimization problems become more complex, better optimization algorithms were needed. BA, bat algorithm is a population based algorithm. BA has been applied to several real-world problems; it is an optimization technique which is well adapted to the optimization of nonlinear functions in multidimensional space. BA, bat algorithm is mainly based on hunting behavior of bats; it is a relatively new population based metaheuristic approach. In this algorithm possible solution of the problem is represented by bat positions. Quality of the solution is indicated by the best position of a bat to find its prey.

Bats are fascinating animals; mainly micro bats use a type of sonar, called, echo location, to detect prey, avoid obstacles, and locate their roosting crevices in the dark. They can emit a very loud and short sound pulse and it hits an object and, after some time it listens for the echo that bounces back from the surrounding objects. Most bats use short, frequency-

modulated signals to sweep through about an octave, and each pulse lasts a few thousandths of a second (up to about 8 to 10 ms) in the frequency range of 25kHz to 150 kHz. Typically, microbats can emit about 10 to 20 such sound bursts every second, and the rate of pulse emission can be speed up to about 200 pulses per second when homing on their prey.

Xin-She Yang (2010) developed the bat algorithm with the following three idealized rules:

1. Echo location is used by all bats to sense distance, and they also being able to distinguish the difference between an obstacle/prey and background barriers in some magical way.

2. Bats fly randomly with velocity v_i at position x_i with a frequency f_{min}, varying wavelength λ and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission r ε [0, 1], depending on the proximity of their target

3. The loudness can vary in many ways; we assume that the loudness varies from a large (positive) A_0 to a minimum constant value $A_{min.}$

Each bat will be having a velocity v_i^t and a position x_i^t, at iteration t, in a d-dimensional search or solution space. Among all the bats, there will be a current best solution x_*. Therefore, the above three rules can be translated into the updating equations for x_i^t and velocities v_i^t [12].

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (3)$$

$$v_i^t = v_i^{t-1} + (x_i^{t-1} + x_*)f_i \quad (4)$$

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

where β ε [0, 1] is a random vector drawn from a uniform distribution. Initially, each bat is randomly assigned a frequency which is drawn uniformly from [f_{min}, f_{max}]. The loudness and pulse emission rates essentially provide a mechanism for automatic control and auto zooming into the region with promising solutions. Researchers shown that although BA finds solutions much faster than most of the contemporary search techniques like Evolutionary and Genetic Algorithm, it usually do not improve the quality of solutions as the number of iterations increase and thus becomes a victim of premature convergence resulting in a suboptimal solution. This drawback of PSO is due to the lack of diversity, which forces the swarm particles to converge to the local optimum.

IV. HAMMING SCAN ALGORITHM

One of the methods for maintaining the diversity of the population is inclusion of the concept of mutation. The mutation is a term metaphorically used for a change in an element in the sequence. In the present work, HSA for mutation is used.

Hamming scan algorithm is a traditional greedy optimization algorithm, which searches in all directions in the neighborhood of the point to minimize the cost function and has fast convergence rate. For maintaining the diversity of the population, one method we include is the concept of mutation, it has the advantage of locally complete rather than random. The mutation is a term, defined as metaphorically used for a change in an element in the sequence. In this technique, HSA for mutation has been used. HSA searches in the neighbourhood of the point in all directions. In HSA, each element of the 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. After mutation if the cost is reduced then the new element is accepted else the original element is retained. This process is recursively applied to all elements in the sequence. Thus, HSA performs search among all the Hamming-1 neighbours of the sequence and selects the one whose cost function value is minimum.

V. WORKING OF BAT ALGORITHM WITH HAMMING SCAN ALGORITHM

In bat algorithm we include hamming scan algorithm, which chooses the bat with maximum fitness when it is iterating, and it initializes its position randomly for increasing the chaos ability of bats. In this algorithm each particle keeps the record of its coordinates in the solution space which are associated with the best solution (fitness) that has achieved by that bat from the beginning. This value is called current global best location x_*. Another best value that is tracked by the BA is the best value obtained so far by any bat in the neighborhood of that bat. This value is called x_{new}. In this algorithm we have a completely connected group that means all the bats share information, any bat knows what is the best position ever visited by any bat in the group.

The basic steps of bat algorithm for the design of binary sequences is as follows

Step1 (Initialization): Initialize the bat population by randomly generating the position and velocity for each particle.

Step 2: Define pulse frequency f_i at their position x_i as per the equations (3), (4) and (5).

Step 3: Initialize pulse rates r_i and the loudness A_i. As the loudness decreases the pulse emission increases.

Step 4: Generate the new solutions by adjusting the frequency.

$$X_{new} = x_{old} + \varepsilon A^t \quad (6)$$

Step 5: Using HSA

a) Generate a new particle by mutating the elements in x_{new} with HSA.

b) Compare x_{new} with new particle and select the one with low cost value.

Step 6: If the stop criterion is satisfied, then stop, else go to Step 4.

VI. IMPLEMENTATION OF MODIFIED BAT ALGORITHM

Binary codes having good auto-correlation properties are synthesized by using Bat 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 with minimum peak sidelobe level is chosen as the best sequence. The simulation was done using MATLAB R2010a. The implementation report for binary sequence of length 126 is given below. The simulation waveforms for above sequences are shown in Fig.4 it can be observed that the binary sequence based on minimum sidelobe amplitude -1 -1 -1 1 -1 1 1 1 -1 1 -1 -1 -1 1 -1 1 1 1 1 1 1 -1 1 -1 -1 1 1 1 -1 1 1 -1 1 1 1 -1 1 -1 1 -1 -1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 -1 -1 1 -1 -1 1 -1 -1 1 -1 1 -1 -1 1 1 1 1 -1 -1 1 -1 1 -1 -1 -1 -1 -1 -1 -1 -1 -1 1 1 1 1 -1 1 1 -1 1 1 -1 1 -1 1 -1 -1 -1 1 1 -1 -1 -1 1 -1 -1 1 1 1 -1 -1 1 1 -1 -1 -1 -1 1 1 1 -1 -1 -1 1 1 1 -1 1 1 -1 . So, the discrimination factor of this sequence is 15.75.

VII. RESULTS

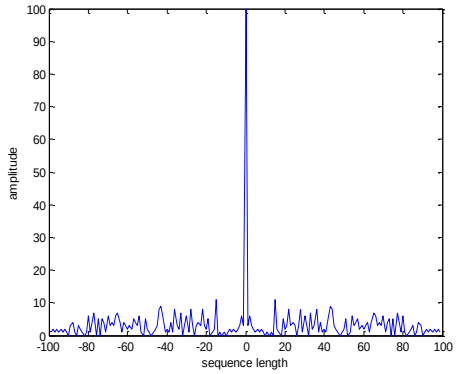

Fig.1. Matlab result for 100-bit Binary Phase Sequence using Bat Algorithm

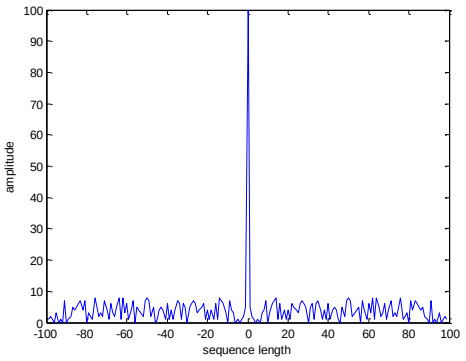

Fig.2. Matlab result for 100-bit Binary Phase Sequence using Modified Bat Algorithm

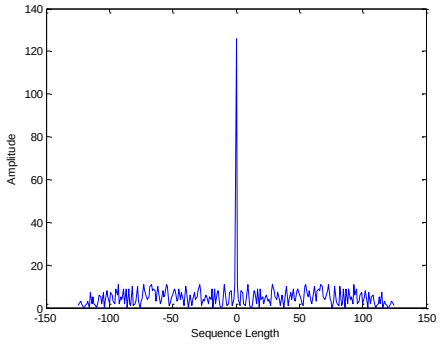

Fig.3. Matlab result for 126-bit Binary Phase Sequence using Bat Algorithm

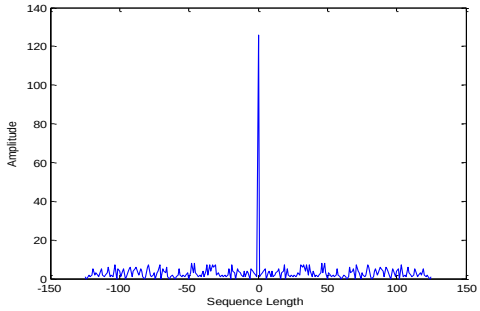

Fig.4. Matlab result for 126-bit Binary Phase Sequence using Modified Bat Algorithm

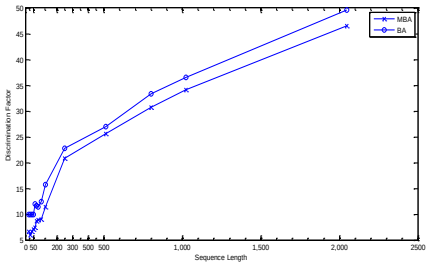

Fig.5. Discrimination Factor values of sequences for various lengths

TABLE 1: DISCRIMINATOR FACTOR (DF) AND MAXIMUM AUTOCORRELATION SIDELOBE PEAKES (ASP) FOR SYNTHESIZED BINARY SEQUENCES WITH BA AND MBA.

Sequence Length	Standard BA		Modified BA	
	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
126	11	11.45	8	15.75
250	12	20.83	11	22.73
512	20	25.60	19	26.95
800	26	30.77	24	33.33
1024	30	34.13	28	36.57
2048	44	46.55	41	49.55

VIII. CONCLUSION

The objective in this paper is mainly to demonstrate the significance of the MBA algorithm in the generation of binary sequences with good discrimination values. These sequences are widely used in radar and spread spectrum communications for improving system performance. The results shown in Table.1 indicate that the proposed algorithm (MBA) outperforms the standard BA, the DF&ASP of standard BA is 11.45 & 11 respectively, whereas the MBA gives DF & ASP as 15.75 & 8 respectively which shows good performance. Unlike in genetic algorithms, in BA, there is no selection operation which increases the speed and reduces complexity of the algorithm. As the sequences length increases the genetic algorithm consumes more time. Hence global optimization techniques such as BA algorithm are used for the generation of sequences with good correlation properties.

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