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Multi-objective Hierarchical Particle Swarm Optimization of Linear Antenna Array with Low Side Lobe and Beam-Width

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Abstract

The main goal of antenna array design is to maximize/minimize the radiation pattern in a particular direction. Thus antenna array is used to reduce the side lobe level (SLL) to optimize the radiated power as possible in a particular direction. In this paper, a multi-objective hierarchal particle swarm optimization (HPSO) algorithm with a multivariate approach to optimize a non-uniform linear array is reported. The HPSO is applied to optimize the SLL and beam width considering the array parameters: element spacing, amplitude excitation and phase variation of elements. These parameters are modified simultaneously to minimize SLL and beam width. It is found that the proposed approach determine SLL of -26 dB and beam width of 18° for an 12 element array, and SLL of -42.5dB and beam width = 1.8° for an 128 element array with low convergence time.

INTRODUCTION

A single antenna is not able to obtain high gain in a particular direction and desired radiation pattern. To solve this problem generally a set of antennas is used instead of a single antenna, these set or group of antenna is called antenna array. When elements of an array are situated in a straight line, then the array is known as a linear array. The radiation pattern of whole array is the product of the radiation pattern of an individual element and the array factor. The side lobe level (SLL) is a main measure in the array and influenced by the excitation (amplitude and phase) & locations of the elements in an array. SLL reduction has an excessive reputation in modern communication systems. It decreases the effect of interference incoming exterior the main lobe. This interference reduction increases the capability of the communication systems. Thus, in antenna array design, it is commonly required to succeed both a low beam width and a low side-lobe level. The optimization technique is a very useful choice for achieving such a goal.

In recent years, many multi-objective optimization techniques were used in the array analysis in several ways to optimize more than one parameter of the array. In [1], multiple-objective genetic optimization has been proposed to optimize array to minimize SLL and beam-width. A multi-objective approach in the linear antenna array design shows that how the design of a linear array can be formulated as an optimization with multiple objective [2]. Cuckoo Search Optimization in [3] is used to determine the optimum excitation element that produces radiation pattern within the boundaries. In [4], Memetic Generalized Differential Evolution is used for minimizing the SLL and the beam-width for 128 element array. A multiple objective optimization method to sub arrayed linear array design is presented in [5]. In [6], particle swarm optimization is applied to optimize a linear and circular array.

In this paper, a multi-objective hierarchical particle swarm optimization technique (HPSO) is presented for reduction of side lobe level as well as narrowing the beam width of the main lobe of a non-uniform linear array. The optimization technique depends on element separation, amplitude excitation & the phase difference between adjacent antenna elements. Each element considered here as an isotropic radiator. Thus radiation pattern of the array depends only on the array factor. The paper is organized as follows: basics of linear antenna array and hierarchical particle swarm optimization have been discussed in Section II and III respectively, array optimization is presented in Section IV, results and discussions are given in Section V, followed by conclusions presented in Section VI.

LINEAR ANTENNA ARRAY

An N element array distributed along z-axis is considered as shown in Fig-1. Array factor of an N element linear is defined by

$$AF(\theta) = 1 + \sum_{i=1}^{N-1} a_i e^{-j(kd_i \cos\theta + \beta_i)} \qquad (1)$$

Where

N = number of elements;

a_i = amplitude excitation of the i^{th} element

d_i = distance between thee i^{th} element and $(i+1)^{\text{th}}$ element

β_i = phase of the i^{th} element

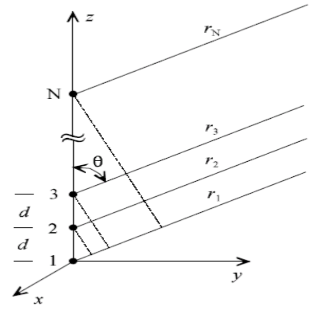

Figure1: Geometry of the N element linear array placed along z-axis.

Radiation pattern of a linear antenna array can be manipulated by adjusting the following three parameters of an array:

1. Separation between two adjacent antenna elements
2. Amplitude excitation of each element
3. Phase excitation of each array elements

A HIERARCHICAL PARTICLE SWARM OPTIMIZATION:

Particle Swarm Optimization (PSO) established by conceptualizing the acting mechanism behind backside process such as flocking birds. The algorithm used to a group of particles flying over the search space to find the global optimum. PSO's basic variant acts by having a group or society (swarm) of particles. Those particles are displaced accordingly by easy formulae. The particle motion is controlled by their own best location (P_{best}) along with the whole swarm's best location (G_{best}). When updated locations are being exposed then particles move toward the swarm's best location. The cycle is continuously repeated and a suitable solution will finally be found. The velocity of any particle depends on its relative position to it's $Pbest$& swarm's $Gbest$ locations as mentioned below.

$$vel_t = w * rand_{no} * vel_{t-1} + C_{pb} * \left(Pbest_{loc_t} - X_{t-1}\right) + C_{gb} * \left(Gbest_{loc_t} - X_{t-1}\right) \quad (2a)$$

Where

$$C_{gb} = accelaration\ coefficient\ associated\ with\ gbest = K_{gb} * rand_{no}$$

$$C_{pb} = accelaration\ coefficient\ associated\ with\ gbest = \mathrm{K_{pb}} * \mathrm{rand_{no}}$$

$$w = Coefficient\ of\ enertia\ weight$$

The calculation of velocity is applied to decide to update the position of the particle. The mathematical expression can be written as;

$$X_t = X_{t-1} + vel_t \quad (2b)$$

In order to enhance search space exploration, self-organizing hierarchical PSO (HPSO) with time varying acceleration coefficients have been introduced [10]. In this HPSO velocity updating equation is as follows

$$vel_t = C_{pb} * \left(Pbest_{loc_t} - X_{t-1}\right) + C_{gb} * \left(Gbest_{loc_t} - X_{t-1}\right) \quad (3a)$$

$$If\ vel_t = 0, vel_t = 2(rand - 0.5)v_r \quad (3b)$$

In this paper a HPSO governed by the equations (2b) and (3) is used to optimize the linear antenna array. A common flow chart to implement the swarm optimization is shown in Fig.-2.

ARRAY OPTIMIZATION

Radiation pattern of an array consists of isotropic radiating elements is solely determined by its array factor. To get the desired radiation patent we need to optimize the array factor. Thus here HPSO is used to optimize the array factor to minimize the SLL and beam-width. Optimization is done in two different ways as mentioned below.

A. Considering one parameter as a variable at a time:

Fitness function for optimization considered here as

$$Fitness\ Function = -max(SLL) * BW \quad (4)$$

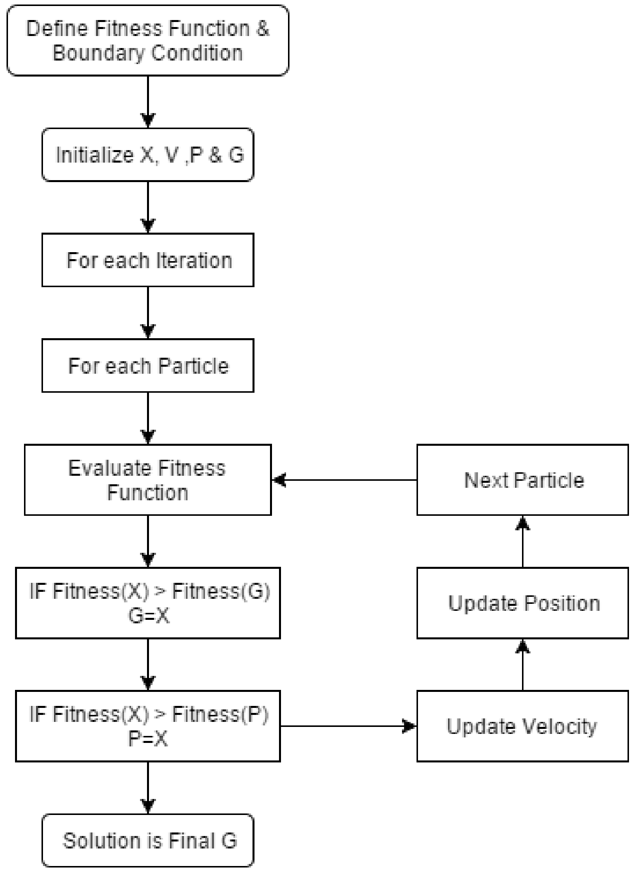

Figure 2: Flow Chart of PSO

Element spacing optimization:

Initially element spacing acts as a variable, whereas amplitude excitation & phase excitation are kept constant. Let amplitude excitation for each element is equal to 1 and phase excitation is zero.

Amplitude excitation optimization:

The second step amplitude excitation is taken as a variable, whereas element spacing & the phase difference of each antenna element is kept constant. The value of element spacing is the optimized result of the previous step and phase excitation is zero.

Phase excitation optimization:

Third step phase excitation is taken as a variable, whereas element spacing & the amplitude excitation of each antenna element are kept constant. The value of element spacing and amplitude excitation are the optimized result of the previous steps.

The initial population is stated as follows:

Number of elements=N
Initial amplitude excitation a_i =1 for i=1, 2, 3…N-1
Initial phase excitation β_i for i=1, 2, 3…N-1.

B. Considering all three parameters as variable simultaneously:

These three optimizations are chosen simultaneously until convergence is achieved. The fitness function is the base of the HPSO; the parameter value will be updated according to Fitness Function

$$Fitness\ function\ =\ -max(SLL) * BW \tag{5}$$

PSO parameters considered here:

Number of trials = 10;

Size of swarm = N-1;

Iteration number = 400;

$Max\ no.of\ Fitness\ Value\ =\ (swarm\ size) *\ iteration$

So Max number of Fitness values =4400;

The problem is formulated and optimization is done for a 12 element and a 128 element non-uniform linear array.

RESULTS AND DISCUSSIONS

The optimized parameters of the array obtained taking only one array parameter as a variable at a time is tabulated in Table I. Considering all the three parameters (element spacing, amplitude excitation and phase excitation of each element) simultaneously optimization has done using HPSO and optimized parameters of the array are tabulated at table-II.

TABLE I

Optimized results for N=12 considering one parameter as a variable at a time

Element Spacing	Amplitude Excitation	Phase
0.3921	0.8039	0.0554
0.4343	0.9460	0.0477
0.3454	0.8625	0.0509
0.3743	1.1059	0.0683
0.3106	0.7578	0.0594
0.3043	0.6794	0.1071
0.2636	0.7094	0.0701
0.3259	0.5992	0.0571
0.2722	0.5876	0.0985
0.3544	0.5888	0.0617
0.4978	0.5099	0.0626

TABLE II

Optimized results for N=12 considering all three variable simultaneously

Element Spacing	Amplitude Excitation	Phase
0.7479	0.8065	0.4998
0.7632	0.8418	0.7851
0.7047	0.8114	0.9217
0.6750	0.8250	0.9608
0.6029	0.8232	1.0861
0.6528	0.8393	1.0200
0.6337	0.8044	0.9693
0.5072	0.8193	0.7779
0.6568	0.8214	0.7704
0.7251	0.8198	0.5912
0.7629	0.8372	0.3387

Radiation pattern of the 12 element array considering the parameters value as mentioned in Table-I and table-II are plotted in Fig-3. Red colored plot is for the parameters mentioned at table-I and violet colored plot is for the parameter tabulated in Table-II. From these two plots it is quite evident that table-II values give better results. It gives both minimum SLL and beam width. Side lobe label obtained here -26 dB and beam width of 18 degree.

Since we get better results when optimization is done considering all three parameters as variable, this optimization technique considering all the parameters simultaneously as variables is applied for an array of 128 elements. Radiation pattern is plotted for a 128 element array taking optimized antenna parameters in Fig-4. Figure shows that a very low SLL of -42.5 dB and beam width of 1.8 degree is achieved for a 128 element array.

Finally a comparison is made between the array pattern of a non-uniform array optimized using Genetic Algorithm [1], NSGA-II method [2], Cuckoo Search [3], MGDE3 [4] and that obtained by the above method in Table III. Table shows that HPSO gives the best results. Same optimization technique can be applied for a linear array consists of practical antenna element. I that case array factor have to be multiplied by the element radiation pattern.

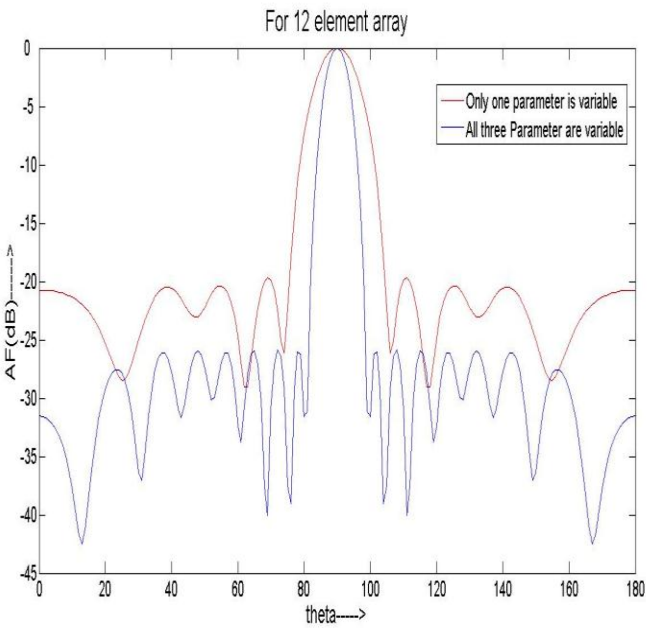

Figure 3: Radiation Pattern of 12 elements array

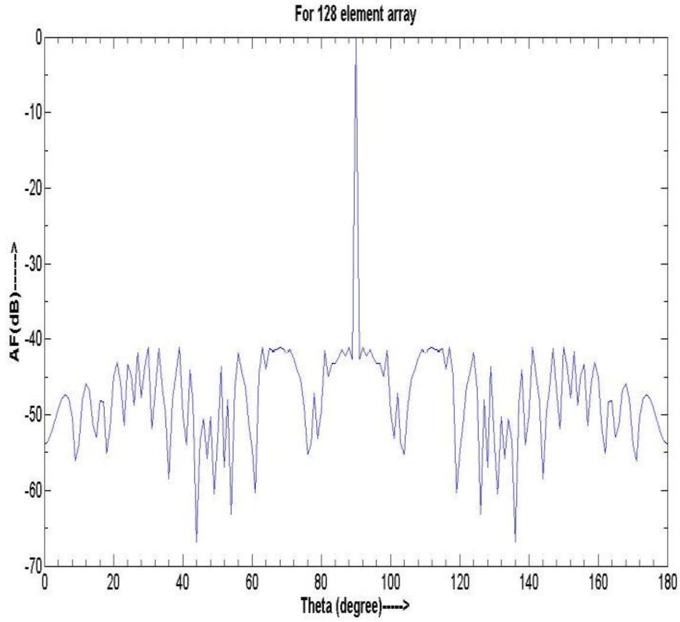

Figure 4: Radiation Pattern of 128 elements array

TABLE III: Comparison of results

Optimization Technique	No of element in the array, N=12		No of element in the array, N=128	
	Minor Lobe (dB)	Beam-width (Degree)	Minor Lobe (dB)	Beam-width (Degree)
GA [1]	-26	19.1	-20.2	1.8
NSGA [2]	-17	20	-	-
Cuckoo Search [3]	-20	42	-	-
MGDE [4]	-	-	-20.16	2
HPSO	-26	18	-42.5	1.8

CONCLUSION

A multi-objective HPSO approach is presented for non-uniform linear antenna array to optimize the side lobe Level (SLL) and beam-width to get high directivity and less interference at low power loss. The fitness function is used to optimize the excitation, element spacing and phase variation of the elements simultaneously. It is found that the proposed approach realizes SLL of -26dB and less beam-width of 18° for N=12-element array, and very low SLL=-42.5dB and narrow beam-width= 1.8° for N= 128-element array with low convergence time (4400 no. of maximum iterations). A comparison is made between optimized results using the HPSO and different techniques available in the literature. Comparison table shows that HPSO gives the best results for both 12 element and 128 element array.

This technique can also be used for planar array and circular array. Time modulated linear array can also be optimized using this technique.

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