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Comparative Analysis of Side Lobe Level Reduction Optimization Algorithms of Linear Antenna Array

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Abstract: Linear antenna array design is one of the most important electromagnetic optimization problems of current interest . In the antenna arrays the side lobe level is main problem which causes wastage of energy. This paper describes the application of a recently developed metaheuristic algorithm ,known as the Particle Swarm Optimization Gravitational Search Algorithm(PSOGSA) to optimize the spacing between the elements of the linear array to produce a radiation pattern with minimum side lobe level. The results of the PSOGSA algorithm have been compared with results obtained using other metaheuristics like the Invasive Weed optimization(IWO),Particle Swarm Optimization(PSO) and Tabu Search (TS) algorithm.

Keywords: Antenna Array,Side lobe level(SLL), Particle Swarm Optimization Gravitational Search Algorithm (PSOGSA) ,Invasive Weed Optimization(IWO),Tabu Search Algorithm(TS),Particle Swarm Optimization(PSO)

I. INTRODUCTION

"An antenna is any device that converts electronic signals to electromagnetic waves (and vice versa)" efficiently with least amount of loss of signals [1].These days, antenna arrays are preferred because the use of a single element has numerous limitations in terms of directivity and bandwidth [2].An antenna array is a configuration of individual radiating elements that are arranged in space and can be used to produce a directional radiation pattern Antenna arrays come in different geometrical configurations[3]. A linear array has all its elements placed along a straight line[4].Side lobe is an important metric used in antenna arrays, and depends on the weight and positions in the array[5]. Several synthesis methods are concerned with suppressing the Side Lobe Level (SLL) whereas preserving the gain of the main beam. For the linear array geometry, this can be done by designing the spacing between the elements, although keeping a uniform excitation over the array aperture. Other methods of controlling the array pattern use non-uniform excitation and phased arrays[3].Different optimization techniques have been adopted to compute the array parameters in order to obtain good radiation pattern having minimum SLL. So far, different algorithms like GA, IWO,TSA,PSO have been effectively applied to different electromagnetic problems including antenna design and array synthesis[6].In this paper, PSOGSA is used to optimize the spacing between the elements of the linear array to produce a radiation pattern with minimum SLL. Three examples of linear antenna array for different number of antenna elements have been used to illustrate the application of the algorithm. Comparison of the PSOGSA algorithm results with the results obtained with other best known metaheuristics like IWO, PSO, TSA, has been presented in this paper. A formulation of the array pattern synthesis as an optimization task has been discussed in Section 2. Section 3 provides a inclusive overview of the PSOGSA algorithm. Experimental settings have been discussed and the results have been presented in Section 4. Section 5 finally concludes the paper and few future research issues.

II. FORMULATION OF THE DESIGN PROBLEM

Consider a linear antenna array, with 2N isotropic radiators positioned symmetrically along the x-axis. The array geometry is shown in Fig.1. The array factor in the azimuth plane can be written as,

$$\mathrm{AF}(\phi) = 2\,.\sum_{n=1}^{N} I_n \cos[k.x_n.\cos(\phi) + \varphi_n] \quad (1)$$

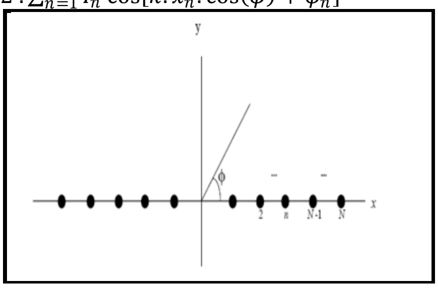

Fig.1. Symmetrically placed linear array [3]

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where k is the wave number, and I_n , φ_n,and x_n are,correspondingly excitation magnitude, phase and location of the n-th element. If we further assume a uniform excitation of amplitude and phase (that is I_n= 1 and φ_n = 0) for all elements), the array factor can be further simplified as [3]:

$$\mathrm{AF}(\phi) = 2 \,.\sum_{n=1}^{N} I_n \cos[k.x_n.\cos(\phi)] \tag{2}$$

Now the statement of the problem, simply reduces to: apply the PSOGSA algorithm to find the locations x_n of the array elements that will result in an array beam with minimum SLL.

For side lobe suppression, the fitness function used is:

$$\mathrm{F} = \sum_i \frac{1}{\Delta\phi_i}\int_{\phi_{li}}^{\phi_{ui}} |AF(\phi)|^2 \, d\phi \tag{3}$$

To minimize SLL we use the above fitness function as and apply PSOGSA to it[3].

III. AN OVERVIEW OF PSOGSA ALGORITHM

In this section, first we provide a brief description of standard PSO and standard GSA and then present an overview of PSOGSA algorithm.

A. Standard Particle Swarm Optimization

The PSO was motivated from social behavior of bird flocking. It uses a number of particles which fly around in the search space to find best solution. For the meantime, they all look at the best particle (best solution) in their paths. In additional words, particles consider their own best solutions as well as the best solution has found so far. Every particle in PSO should consider the current position, the current velocity, the distance to pbest, and the distance to gbest to modify its position. PSO was mathematically modeled as follow[7]:

$$v_i^{(t+1)} = wv_i^t + c_1 \times rand \times (pbest_i - x_i^t) + c_2 \times rand \times (\mathrm{gbest} - x_i^t) \tag{4}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{5}$$

Where v_i^t is the velocity of particle i at iteration t, w is a weighting function,c_j is a weighting factor,rand is a random number between 0 and 1,x_i^t is the current position of particle i at iteration t,$pbest_i$ is the pbest of agent i at iteration t, and gbest is the best solution .The first part of (4) ,wv_i^t ,provides exploration ability for PSO.The second and third parts,c_1×rand×($pbest_i$ -x_i^t) and c_2 ×rand × ($gbest_i$ -x_i^t),represent private thinking and collaboration of particles.The PSO starts randomly placing the particles in a problem space.In every iteration ,the velocities of paricles are calculated using (4).After defining the velocities,the position of masses can be calculated as (5). The process of changing particles' position will continue until meeting an end criterion[7].

B. Standard Gravitational Search Algorithm

GSA is an optimization method and the basic physical theory which GSA is inspired from is the Newton's theory that states: Each particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. GSA can be considered as a collection of agents whose have masses proportional to their value of fitness function. Throughout generations, all masses attract each other by the gravity forces between them. A heavier mass has the bigger attraction force. Consequently, the heavier masses which are possibly close to the global optimum attract the other masses proportional to their distances. The GSA was mathematically modeled as follow. Suppose a system with N agents. The algorithm starts with randomly placing all agents in search space. During all epochs, the gravitational forces from agent j on agent i at a specific time t is defined as follow [7]:

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)\times M_{aj}(t)}{R_{ij}(t)+\mathcal{E}}(x_j^d(t) - x_i^d(t)) \tag{6}$$

Where M_{aj} is the active gravitational mass related to agent j, M_{pi} is the passive gravitational mass related to agent i,G(t) is gravitational constant at time t,Ɛ is a small constant, and $R_{ij}(t)$ is the Euclidian distance between two agents i and j.

The G(t) is calculated as (7)

$$\mathrm{G(t)} = G_0 \exp\Big(-\alpha \times \\ itermaxiter \tag{7}$$

Where α and G_0 are descending coefficient and initial value respectively, iter is the current iteration, and maxiter is maximum number of iterations. In a problem space with the dimension d, the total force that acts on agent i is calculated as the following equation[7]:

$$F_i^d(t) = \sum_{j=1, j\neq i}^{N} rand_j \, F_{ij}^d\,(t) \tag{8}$$

Where $rand_j$ is a random number in the interval[0,1].According to the law of motion ,the acceleration of an agent is proportional to the result force and inverse of its mass, therefore the acceleration of all agents should be calculated as follow[7]:

$$ac_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \tag{9}$$

Where t is a specific time and M_i is the mass of object i. The velocity and position of agents are calculated as follow[7]:

$$vel_i^d(t+1) = rand_i \times vel_i^d(t) + ac_i^d(t) \tag{10}$$

$$x_i^d(t) = x_i^d(t) + vel_i^d(t+1) \tag{11}$$

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Where $rand_i$ is a random number in the interval [0,1]. In GSA, at first all masses are initialized with random values. Each mass is a candidate solution. Following initialization, velocities for all masses are defined using (10). In the interim the gravitational constant, total forces, and accelerations are calculated as (7), (8), and (9) correspondingly. The positions of masses are calculated using (11). Finally, GSA will be stopped by meeting an end criterion [7].

C. THE HYBRID PSOGSA ALGORITHM

In the hybrid PSOGSA, we hybridize PSO with GSA using low-level co evolutionary heterogeneous hybrid.The hybrid is low-level because we combine the functionality of both algorithms.The basic idea of PSOGSA is to combine the ability of social thinking (gbest) in PSO with the local search capability of GSA. In order to combine these algorithms, (12) is proposed as follow[7]:

$$v_i(t+1) = w \times v_i(t) + c_1' \times rand \times ac_i(t) + c_2' \times \text{rand} \times (\text{gbest-}X_i(t) \qquad (12)$$

Where $v_i(t)$ is the velocity of agent i at iteration t, c_j' is a weighting factor,w is a weighting function, and is a random number between 0 and 1, $ac_i(t)$is the acceleration of agent i at iteration t,and gbest is the best solution[7].

In each iteration, the positions of particles are updated as follow:

$$X_i(t+1) = X_i(t+1) = X_i(t) + V_i(t+1) \qquad (13)$$

In PSOGSA, at first, all agents are randomly initialized. Every agent is considered as a candidate solution. After initialization, Gravitational force, gravitational constant, and resultant forces among agents are calculated using (6), (7), and (8) respectively. After that, the accelerations of particles are defined as (9). In every one iteration, the best solution until now should be updated. After calculating the accelerations and with updating the best solution so far, the velocities of all agents can be calculated using (12). Finally, the positions of agents are defined as (13). The procedure of updating velocities and positions will be stopped by gathering an end criterion[7]. The flowchart of PSOGSA are represented in fig.2.[7].

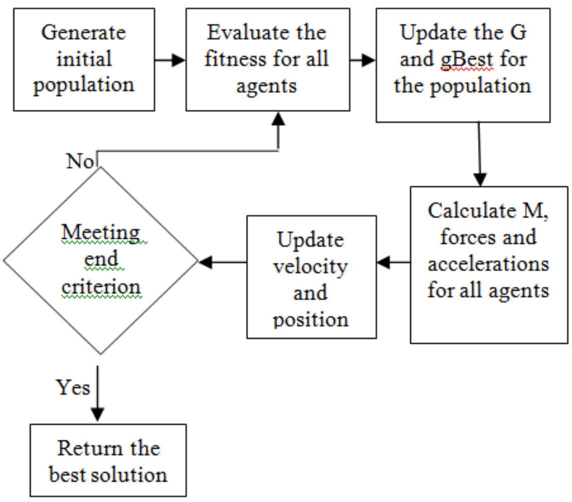

Fig.2. Flowchart of PSOGSA [7]

IV. EXPERIMENTAL RESULTS

Here we have used PSOGSA Optimization algorithm for SLL reduction of linear antenna array. The results have been compared with that of Tabu Search Algorithm (TSA),Invasive Weed optimization(IWO),and Particle Swarm Optimization (PSO).For PSOGSA we use the following simulation parameters: Population size=30,$c_1' = 0.5, c_2' = 1.5$, w is any random number in [0, 1], Gravitational constant, $G_0 = 1, \alpha = 20$,maximum iteration =1000, and Stopping criteria=maximum iteration. For rest of the competitor algorithms, we used the best possible parametric setup as explained in their respective literatures [3]. All simulation results have been plotted as the Gain versus Azimuth Angle plot. In the first example PSOGSA were used to design 12 element array for minimum SLL.

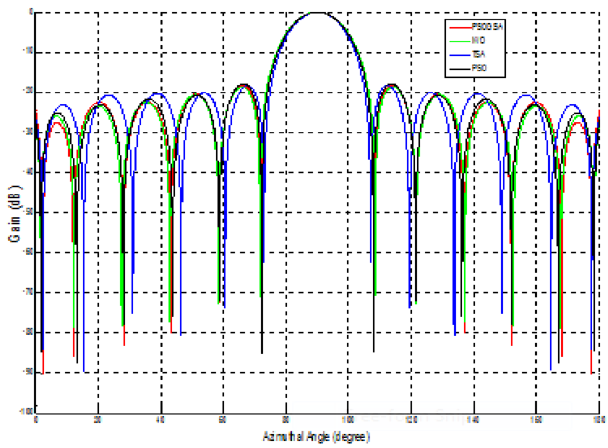

Fig.3.Array patterns obtained for the Example 1

The array pattern for 12 antenna elements from the PSOGSA algorithm is shown in Fig.3., along with patterns obtained using other competitive metaheuristics.From Fig.3 it is evident that PSOGSA has minimized SLL to the greatest extent.

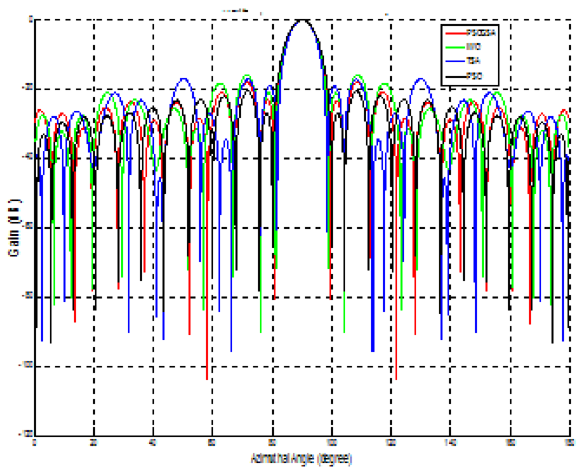

Fig.4. Array patterns obtained for the Example 2

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In the second example, 22 element array has been designed for minimum SLL.The array pattern from the PSOGSA algorithm is shown in Fig.4, along with patterns obtained using other competitive metaheuristics. From Fig.4 it is apparent that PSOGSA has minimized SLL to the greatest extent. In the Fig.4, first side lobe level using PSOGSA algorithm is -23.33dB and using IWO is -20.41dB and using TSA is -19.17 dB and using PSO is -26.92 dB. PSOGSA has lower SLL as compare to IWO and TSA.

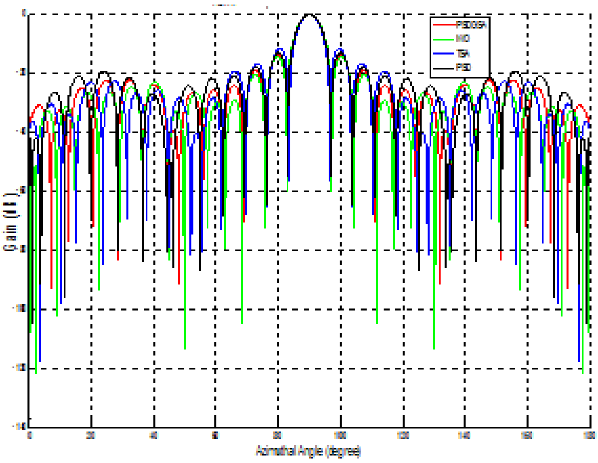

Fig.5. Array patterns obtained for the Example 3

In the third example, 26 element array has been designed for minimum SLL.Fig.5 show that PSOGSA has successfully minimized the side lobe level. The array pattern from the PSOGSA algorithm is shown in Fig.5, along with patterns obtained using other competitive metaheuristics. As shown in the Fig.5 the SLL value for PSOGSA algorithm is lower as compare to PSO and TSA algorithm.

V. CONCLUSION

This paper illustrated the use of the PSOGSA algorithm for the Side Lobe Level reduction of linear antenna array geometry.PSOGSA was successfully used to optimize the locations of array elements to demonstrate an array pattern with suppressed side-lobes. In each of these cases, the PSOGSA algorithm easily achieved the optimization goal. The results obtained using PSOGSA algorithm has been compared with the PSO,IWO and TSA algorithms results. Future research may focus on achieving more control of the array pattern by using the PSOGSA algorithm to optimize, not only the location, but also the excitation amplitude and phase of each element in the array, and exploring other array geometries.

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BIOGRAPHIES

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