Patterns Antennas Arrays Synthesis Based on Adaptive Particle Swarm Optimization and Genetic Algorithms

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Abstract

In recent years, evolutionary optimization (EO) techniques have attracted considerable attention in the design of electromagnetic systems of increasing complexity. This paper presents a comparison between two optimization algorithms for the synthesis of uniform linear and planar antennas arrays, the first one is an adaptive particle swarm optimization (APSO) where the inertia weight and acceleration coefficient are adjusted dynamically according to feedback taken from particle's best memories to overcome the limitations of the standard PSO which are: premature convergence, low searching accuracy and iterative inefficiency. The second method is the genetic algorithms (GA) inspired from the processes of the evolution of the species and the natural genetics.

The results show that the design of uniform linear and planar antennas arrays using APSO method provides a low side lobe level and achieve faster convergence speed to the optimum solution than those obtained by a GA.

Keywords: *antennas arrays, planar arrays, synthesis, optimization methods; adaptive particle swarm algorithm, genetic algorithm.*

1. Introduction

Planar antenna arrays have been widely studied due to their importance in communications industry such us mobile, wireless communication, and other domains [1], in order to seek for an optimal planar antenna arrays feed laws so that the array complies with the requirements of the user and according to precise specifications, such us lower side lobes of planar antenna array pattern, controllable beamwidth, and the pattern symmetry in azimuth angles. The traditional optimization methods cannot bear the demand of such complex optimization problem. Particles Swarm Optimization (PSO) [2] is an evolutionary algorithm based on the swarm intelligence. Eberhart and Kennedy first introduced such algorithms in 1995. The original conception comes from the research of food hunting by birds. PSO algorithm can be used to solve the complex global optimization problems. Currently, the algorithm and its variations are applied to solve many practical problems. For the optimization of the antenna array, the parameters affecting antenna pattern are chosen as the design variables [3]. A desired pattern is presented according to the radiate requirement.

The simulation result show that the calculated pattern approaches the desired pattern and the SLL is very low. This kind of optimization improves the efficiency of antennas array.

2. Standard Particle Swarm Optimization

Recently, the PSO technique has been successfully applied to the design of antennas and microwave components [4-5]. The results proved that this method is powerful and effective for optimization problems. PSO is similar in some ways to Genetic Algorithms (GA) and other evolutionary algorithms, but requires less computational bookkeeping and generally fewer lines of code, including the fact that the basic algorithm is very easy to understand and implement. In the PSO mechanism, each potential solution of optimization problem is a bird in the solution space, which called "particle". Each particle has a value of fitness determined by objective functions. They also have a directional velocity to control its move tracks. The particles chase the optimal solution by searching the solution space. All particles have initial positions and velocities [6], where the positions and velocities are iterated. In each iteration, two "best position" are chased to update the particle. The first is the optimal solution found by particle, which called personal best position. The other is the optimal solution in the entire group, which called global best position. In PSO, the i -th particle in the solution space is determined by a fitness function's value. The fitness function is the optimal target, the position of ith particle can be presented by $x_i = (x_{i1}, x_{i2}, ..., x_{id})$, $v_i = (v_{i1}, v_{i2}, ..., v_{id})$ stand for the velocity of the ith particle, the optimal solution come into being through iterative searching, the positions and velocities of particles update by personal and global best positions in each iteration. Let $p_i = (p_{i1}, p_{i2}, \dots, p_{id})$ be the position vector for an individual particle's best fitness, which is personal best position, and $g_i = (g_{i1}, g_{i2}, \dots, g_{id})$ be the global best position among all the agents. The positions and velocities of particles are updated according to the following equations (1) and (2) [7]:

$$v_{id} = \omega \times v_{id} + c_1 \times r_1 \times (p_{id} - x_{id}) + c_2 \times r_2 \times (g_{id} - x_{id}) \quad (1)$$

$$x_{id} = x_{id} + v_{id} \quad (2)$$

Where $\omega = 0.7$ is the inertia weight, c_1 and c_2 are the acceleration coefficients set to 1.7, r_1 and r_2 are random numbers in the range [0,1], The first part of (1) is the initial velocities of particles, the second part is "cognition", which expresses the cogitation of particles; the third part is "social", which expresses the registration of message and cooperation among particles.

The steps involved in standard PSO are shown by the flowchart drawn in figure 1.

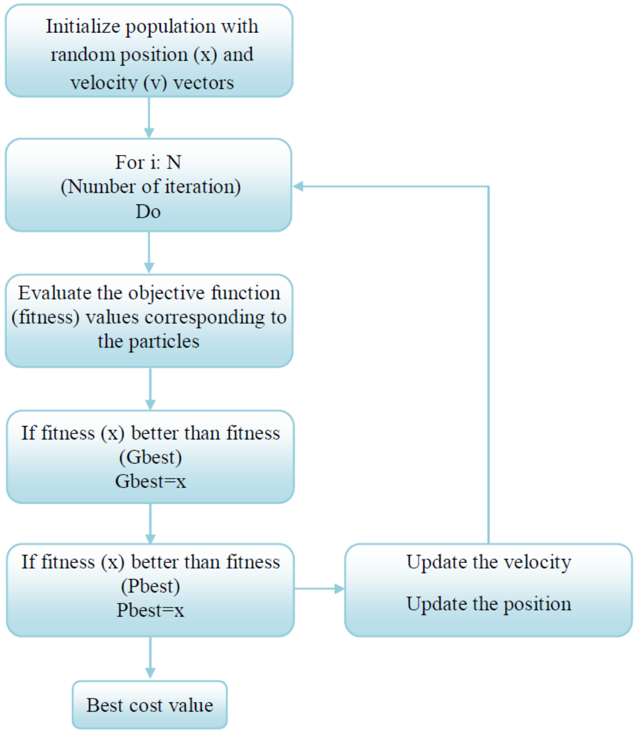

Fig. 1.Flowchart of PSO algorithm

3. Adaptive Particle Swarm Optimization

In this paper, the inertia weight and the acceleration coefficient are neither set to a constant value nor set as a linearly decreasing time varying function [8]. Instead they are defined as a function of local best (pbest) and global best (gbest) values of the fitness function of a minimization problem as given in Eqs. (3) and (4). The average of all the personal best values in that particular generation is termed as ((pbesti)average).

$$\text{Inertia weight,} \quad \omega_i = \left(1.1 - \frac{gbest}{(pbest_i)_{average}}\right) \quad (3)$$

Acceleration coefficient;

$$ac = ac_1 = ac_2 = \left(1 + \frac{gbest}{(pbest_i)}\right) \quad (4)$$

The inertia weight in (3) is termed global-average local best IW (GLbestIW) and the acceleration coefficient in (4) is called global-local best AC (GLbestAC).

4. Genetic Algorithm

By analogy with natural selection and evolution, in classical GA the set of parameters to be optimized (genes) defines an individual or potential solution X (chromosome) and a set of individuals makes up the population, which is evolved by means of the selection, crossover, and mutation genetic operators. The optimization process used by the GA follows the next steps [9].

The genetic algorithm generates individuals (amplitude excitations and phase perturbations of the antenna elements). The individuals are encoded in a vector of real numbers, that represents the amplitudes, and a vector of real numbers restrained on the range (0, 2π), that represents the phase perturbations of the antenna elements. Each individual generates an array factor of certain characteristics of the side lobe level and the directivity. Then, the genetic mechanisms of crossover, survival and mutation are used to obtain better and better solutions. The genetic algorithm evolves the individuals to a global solution that generates an array factor with minimum side lobe level and maximum directivity in the steering direction [10-11].

The steps involved in GA are shown by the flowchart drawn in figure 2.

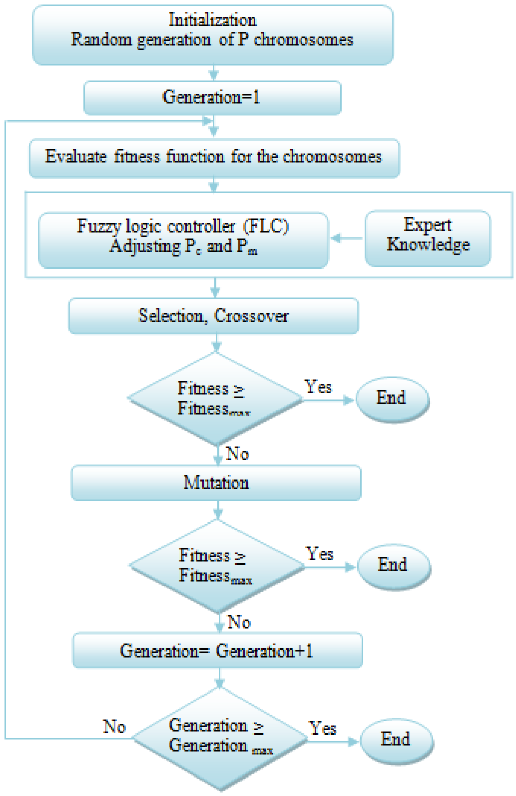

Fig. 2 Flowchart of GA algorithm

5. Linear Antenna Arrays Synthesis

In this section, the APSO and GA algorithms were implemented for the synthesis of uniformly spaced linear array constituted with 16 rectangular microstrip antennas (figure 3). Two examples of linear antenna array synthesis have been considered, the first one by optimizing only excitation weights for a desired radiation pattern specified by a symmetrical narrow beam pattern with a beam width of 8 degrees and maximum side lobe levels of -20dB. The second example for the same desired radiation pattern but pointed at 10°, the synthesis was carried out by optimizing both amplitude and phase weights. In our simulation, we have used a population size of 40 for GA.

For APSO, it set with adapting inertial weight and acceleration coefficients which is proposed by Ratnaweera and Halgamuge [12] and a population size equal to 30 individuals.

In figure 4 we present the result of the first example of linear antenna array synthesis by the optimization of amplitude excitation coefficients using both APSO and GA. It is clearly seen that the radiation pattern obtained by APSO meet better the desired pattern than the obtained by the GA. The side lobe level obtained by APSO optimization (-40dB) are much better than in the case of GA (-23dB).

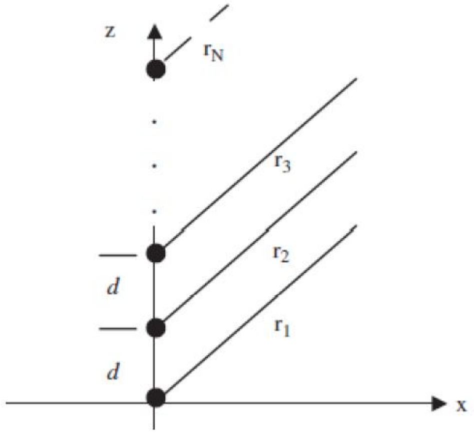

Fig. 3 Linear antennas array.

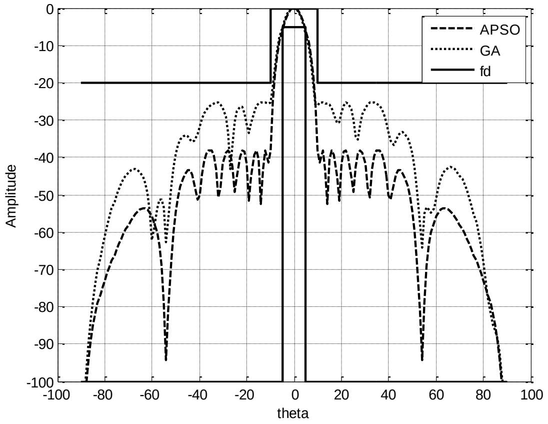

Fig. 4 Result of a linear array synthesis with 16 elements applying both APSO and GA.

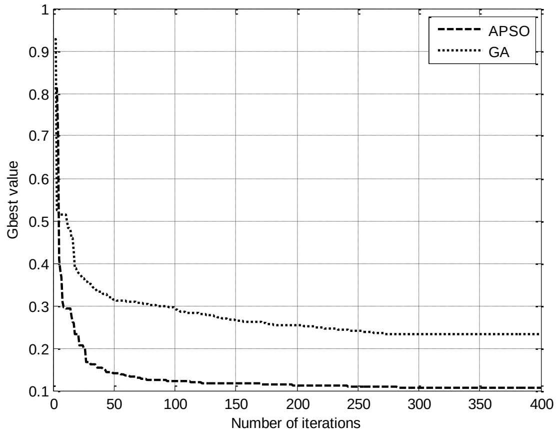

Fig. 5 Fitness evolution of APSO and GA algorithms

From figure 5, the speed approaching the global optimal of APSO is much quickly than that of GA, and the fitness values of the best individuals of APSO are almost higher than that of GA in every population.

In the second example, the synthesis result of a linear array with 16 uniformly spaced antennas for a desired radiation pattern, similar to the previous one but pointed at 10 degrees are shown in figures 6 and 7.

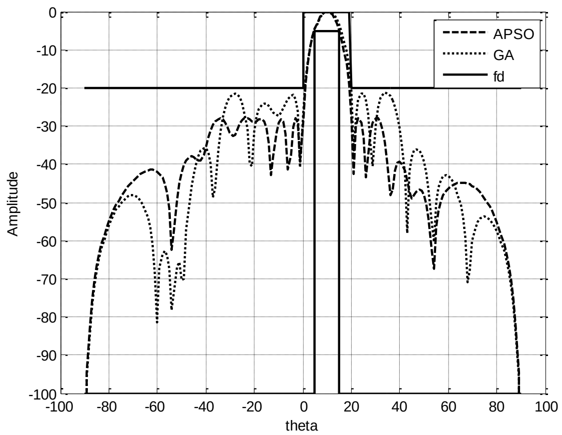

Fig. 6 Result of a linear array synthesis with 16 elements applying both APSO and GA.

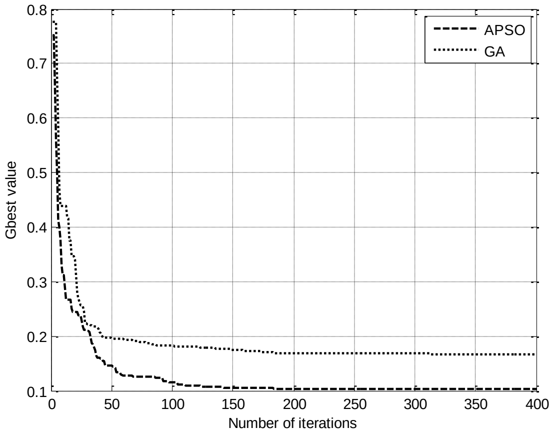

Fig. 7 Fitness evolution of APSO and GA algorithms

6. Planar Antenna Arrays Synthesis

A microstrip antenna have limited radiation diagram however, when we have an aggregate the performance of radiation diagram will be remarkable [13]. Let us consider a planar antenna array constituted of MxN equally spaced rectangular antenna arranged in a regular rectangular array in the x-y plane, with an inter-element spacing of $d = dx = dy = \lambda/2$ (figure 8), and whose outputs are added together to provided a single output. Mathematically, the normalized array far-field pattern is given by:

$$F_s(\theta,\varphi) = \frac{f(\theta,\varphi)}{F_{s\max}} \sum_{n=1}^{M} I_{mn} e^{\left(j(m-1)k_0 \sin\theta \cos\varphi dx + j\psi_{mn}\right)} \cdot \sum_{n=1}^{N} e^{\left(j(n-1)k_0 \sin\theta \sin\varphi dy + j\psi_{mn}\right)} \tag{5}$$

Where

$f(\theta,\varphi)$: Represents the radiation pattern of an element.

I_{mn}: Amplitude coefficient at element *(m, n).*

ψ_{mn} : Phase coefficient at element *(m, n).*

k_0 : Wave number.

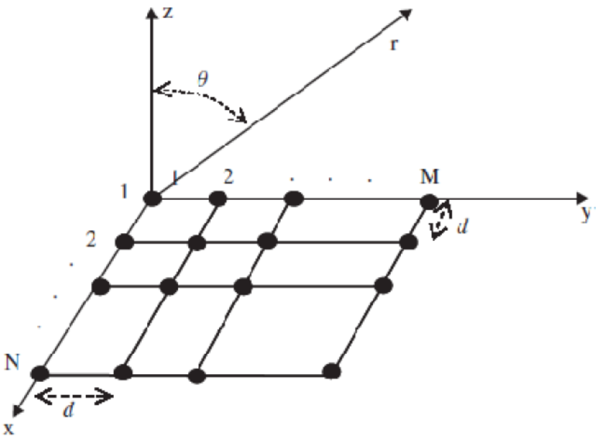

Fig. 8 Planar antennas array.

We use the APSO algorithm to find the appropriate excitation coefficients (amplitude and phase), which shall satisfy the desired radiation pattern.

We have chosen a suitable fitness functions that can guide the APSO optimization toward a solution that meets the desired radiation pattern. The fitness function to be minimized is selected from the work of Chuan Lin [14] which is described by the equation below

$$f(\bar{\rho}) = \mathrm{Max}_{\theta\in S} \left| \frac{A_F^{\bar{\rho}}(\theta)}{A_F^{\bar{\rho}}(\theta_0)} \right| \tag{6}$$

Where S is the space spanned by the angle θ excluding the mainlobe and ρ represents the unknown parameter vector, such as element positions and phases. This objective function minimizes all the sidelobe levels and maximizes the power in the main lobe located at $\theta=\theta_0$.

We implemented the two algorithms APSO and GA for the synthesis of uniformly spaced planar array of 16 rectangular patch antennas. Figures 9 and 11 represent respectively the synthesis result of our array constituted of 16 elements. It is a question respectively of the amplitude and phase optimization and the amplitude and phases pointed at 10 degree in order to as well as possible approach the radiation pattern resulting from a desired template specified by a symmetrical narrow beam pattern with a beam width of 8 degrees and maximum side lobe levels of -20dB. During the simulation we have used a population size of 40 for FGAs. Roulette strategy for "selection" one–point crossover and mutation to flip bits, the value of crossover and mutation probabilities (p_c and p_m) are determined according to FLC.

The figures represent the results of plane array synthesis consisted of 16 aerial elements.

It is noticed that the radiation pattern are contained within the limits imposed by the template and the maximum of side lobes level is lower than -20 dB in such way that the APSO is better than GA and reaches them respectively -35dB and -25 dB (figure 7), -30dB and -22dB (figure 9)

With each diagram, on associates the evolution of the quadratic error during the generations (figure 10 and 12). From this figures the best fitness obtained by the APSO is better than the obtained by the GA.

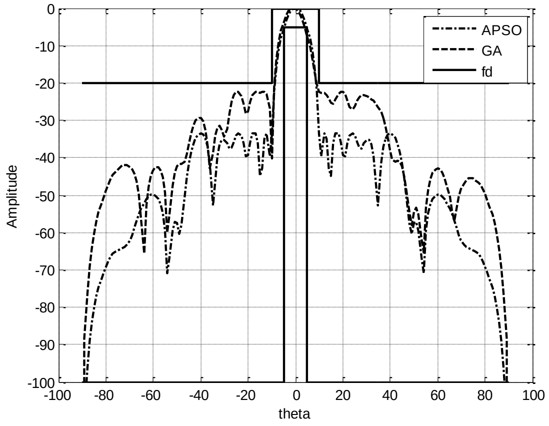

Fig. 9 Result of a linear array synthesis with 16 elements applying both APSO and GA (only amplitude synthesis).

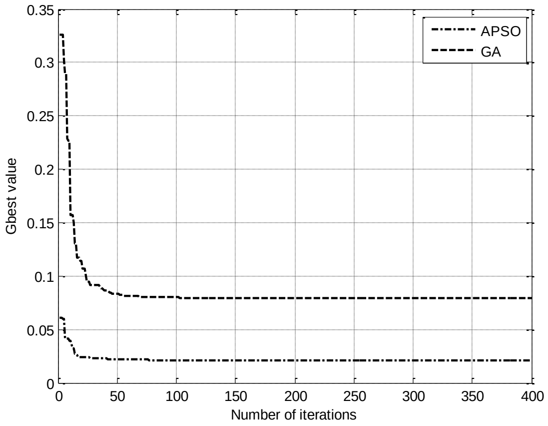

Fig. 10 Fitness evolution of APSO and GA algorithms

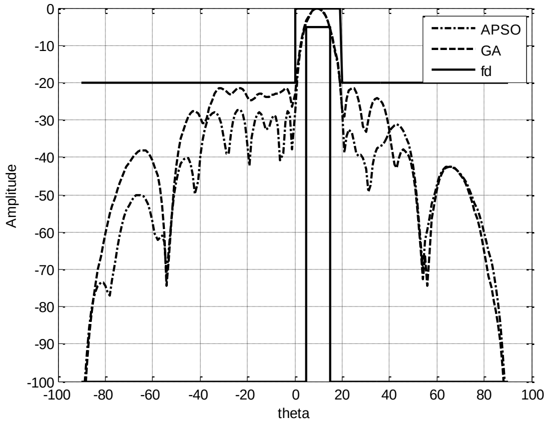

Fig. 11 Result of a linear array synthesis with 16 elements applying both APSO and GA (amplitude and phase synthesis).

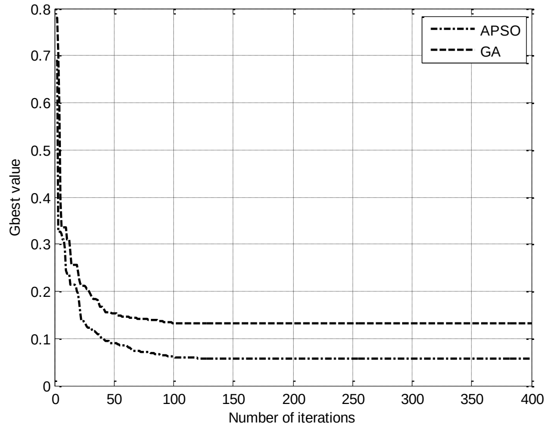

Fig. 12 Fitness evolution of APSO and GA algorithms

7. Conclusion

The optimization techniques seemed APSO and GA for the goal to obtain the global minimum and to avoid remaining to trap in a local minimum like in the case of the deterministic methods. However they present a major disadvantage which lies in their calculative cost and which believes according to the dimension of the problem considered and its difficulty.

The advantage of PSO on GA of is marked as much than the optimization variables number is important. Indeed for a synthesis of antennas array, GA requires an enormous computing time, because this one needs a great iteration number to converge towards an optimal solution.

Included examples on linear and planar antennas array synthesis demonstrate that PSO with adaptive scheme shows better performance than GA because of its simplicity in implementation and minor computing time.

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