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APPLICATION OF THE INVASIVE WEED OPTIMIZATION TECHNIQUE FOR ANTENNA CONFIGURATIONS

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Abstract—In this paper a novel numerical optimization technique for antenna configurations is introduced. This algorithm is inspired from colonizing weeds, which is shown to be very robust and adaptive to changes in the environment. Thus, capturing their properties would lead to a powerful optimization algorithm. The feasibility, efficiency and effectiveness of the proposed algorithm for optimization of antenna problems are examined by a set of antenna configurations. The obtained results are compared with a particle swarm optimization technique which is widely used in antenna optimization. Numerical results show that there is a good agreement between the corresponding results.

1. INTRODUCTION

Antenna design problems and applications always involve optimization processes that must be solved efficiently and effectively. To solve an antenna problem, an engineer must envisage a proper view of the problem in his/her hand. So, the design is the struggle of the designer for finding a solution which best suits the sketched view. In support of this need, there have been various optimization techniques proposed by antenna designers.

Recently, in the literature there has been a considerable attention paid to algorithms inspired from natural processes in order to solve an antenna optimization problem. Genetic algorithm [1–5], Particle swarm optimization [6–9] and ant colony [10, 11] are such methods that have already been used in antenna optimization problems.

In this paper a novel numerical stochastic optimization method inspired by colonizing weeds has been introduced for optimizing antenna problems. This algorithm has been first used by Mehrabian and Lucas [12] in dynamic and control systems theory. They have named the algorithm Invasive Weed Optimization (IWO). In order to show the efficiency of IWO four antenna configurations have been successfully optimized by this method.

2. INVASIVE WEED OPTIMIZATION ALGORITHM

To simulate the colonizing behavior of weeds some basic properties of the process is considered below [12]:

1) A finite number of seeds are being spread out over the search area.
2) Every seed grows to a flowering plant and produces seeds depending on its fitness.
3) The produced seeds are being randomly dispersed over the search area and grow to new plants.
4) This process continues until maximum number of plants is reached; now only the plants with lower fitness can survive and produce seeds, others are being eliminated. The process continues until maximum number of iterations is reached and hopefully the plant with the best fitness is closest to the optimal solution. The process is addressed in details as follows:

2.1. Initialize a Population

A population of initial solutions is being spread out over the d dimensional problem space with random positions.

2.2. Reproduction

A certain population of plants is allowed to produce seeds depending on its own and the colony's lowest and highest fatnesses: the number of seeds each plant produces increases linearly from the minimum possible seed production to its maximum level. In other word, a plant will produce seeds based on its fitness, the colony's lowest fitness and highest fitness to make sure the increase is linear.

2.3. Spatial Dispersal

Randomness and adaptation in the algorithm is provided in this part. The generated seeds are being randomly distributed over the d dimensional search space by normally distributed random numbers with the mean value equal to zero, but with a varying variance. This ensures that the seeds will be randomly distributed such that they abide near the parent plant. However, standard deviation (SD), σ, of the random function will be reduced from a previously defined initial value, $\sigma_{initial}$, to a final value, σ_{final}, in every step (generation). In simulations, a nonlinear variation has shown satisfactory performance, which is given in Eq. (1)

$$\sigma_{iter} = \frac{(iter_{\max} - iter)^n}{iter_{\max}^n}(\sigma_{initial} - \sigma_{final}) + \sigma_{final} \tag{1}$$

where $iter_{\max}$ is the maximum number of iterations, σ_{iter} is the SD at the present step and n is the nonlinear modulation index.

2.4. Competitive Exclusion

If a plant leaves no offspring then it would go extinct, otherwise they would take over the world. Thus, there is a need for some kind of competition between plants for limiting the maximum number of plants in a colony. After passing some iterations, the number of plants in a colony will reach its maximum level by fast reproduction, however, it is expected that the fitter plants have been reproduced more than the undesirable plants. By reaching the maximum number of plants in the colony ($P_{\max}$), a mechanism for eliminating the plants with poor fitness in the generation activates. The elimination mechanism works as follows: when the maximum number of weeds in a colony is reached, each weed is allowed to produce seeds according to the mechanism mentioned in the Section 2.2. The produced seeds are then allowed to spread over the search area according to Section 2.3. When all seeds have found their position in the search area, they are ranked together with their parents (as a colony of weeds). Next, the weeds with lower fitness are eliminated to reach the maximum allowable population in a colony. In this way, the plants and offsprings are ranked together and the ones with better fitness survive and are allowed to replicate. The population control mechanism is also applied to their offspring up to the end of a given run, realizing competitive exclusion.

3. ANTENNA CONFIGURATIONS OPTIMIZATION USING IWO

In this section four antenna configurations are optimized by IWO. The reason of this selection has been explained with details in [13]. These configurations have been optimized there with other optimization techniques like GA and PSO. We have used FEKO software for analysis of selected antennas. The IWO code was written in MATLAB software. Each configuration is optimized according to the algorithm described in Section 2.

3.1. Configuration 1: Maximization of the Directivity of a Length-Varying Dipole [14]

The first problem proposed based on the radiation characteristics of a finite-length thin-wire dipole (Fig. 1). As the length of the dipole increases, its radiation pattern becomes more directional, but when the length is greater than approximately one wavelength, the directional properties are lost, due mainly to the grating lobes and increasing side lobe level. The wire dipoles are simulated with FEKO. The radius of the wires is 0.001λ. The search space is formed for the length of the dipoles varying from 0.5λ to 3λ and the observation angle is set at $\pi/2$ radians. IWO parameters which are used for optimization configuration 1 are shown in Table 1. The length and directivity variations versus number of iterations are shown in Figs. 3 and 4, respectively. As shown in these figures the optimized value of directivity is 5.15 dBi which corresponds to the dipole length of 1.26λ. The same results are obtained with Particle Swarm Optimization (PSO). The run time of the programs on a Pentium IV with 2 GB of RAM for IWO and PSO are 25.6 seconds and 28.1 seconds, respectively.

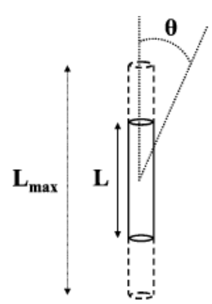

Figure 1. Length-varying dipole geometry.

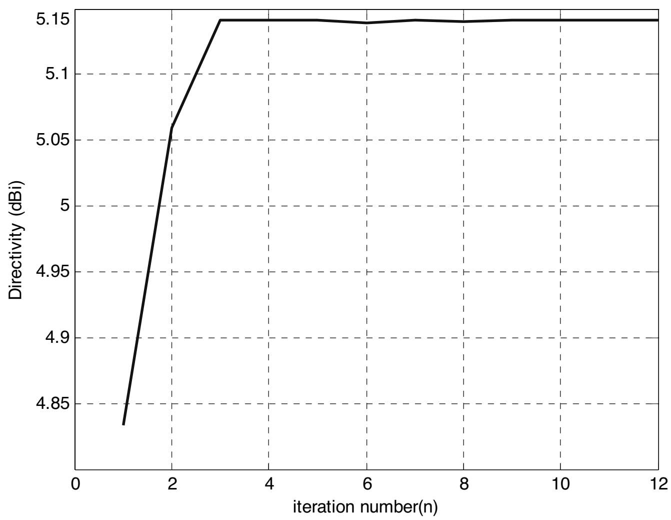

Figure 2. Directivity of dipole versus IWO iteration number.

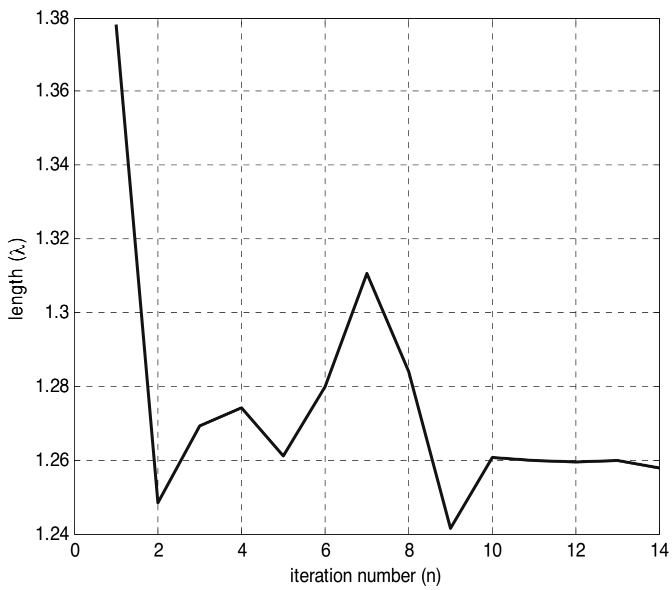

Figure 3. Length of dipole versus IWO iteration number.

Table 1. IWO parameters values for configuration 1.

Symbol	Quantity	Value
No	Number of initial population	5
$it_{\max}$	Maximum number of iterations	100
dim	Problem dimension	1
$P_{\max}$	Maximum number of plant population	5
$S_{\max}$	Maximum number of seeds	25
$S_{\min}$	Minimum number of seeds	0
n	Nonlinear modulation index	3
$\sigma_{initial}$	Initial value of standard deviation	2
σ_{final}	Final value of standard deviation	0.01
L_{ini}	Initial search area	0.5λ to 3λ

3.2. Configuration 2: Maximization of the Directivity of a Uniform Linear Array of Half-wavelength Dipoles [14, 15]

In order to maximize the directivity of the array, we consider an array of 10 dipoles contained in the XZ plane as shown in Fig. 4, where the elements are fed at their centers with a unit amplitude voltage source. The directivity at the angle $\theta = \pi/2$ and $\varphi = \pi/2$ are maximized for different values of spacing between the dipoles. The spacing between elements varies from 5λ to 15λ. IWO parameters which are used for optimization configuration 2 are shown in Table 2. Spacing and directivity variations of linear array versus number of iterations shown in Figs. 5 and 6, respectively. As shown in these figures the optimized value of directivity is about 2.5 dBi, which corresponds to the spacing of 5.8λ. The same results are obtained with Particle Swarm Optimization (PSO). The run time for IWO and PSO are 60 seconds and 52 seconds respectively.

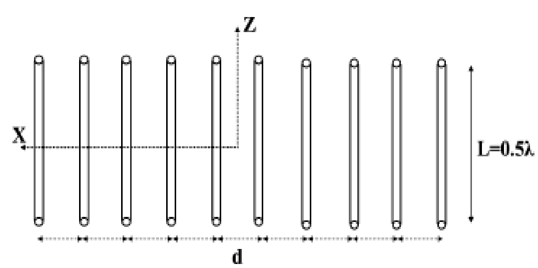

Figure 4. Linear array of 10 half-wavelength dipoles [13].

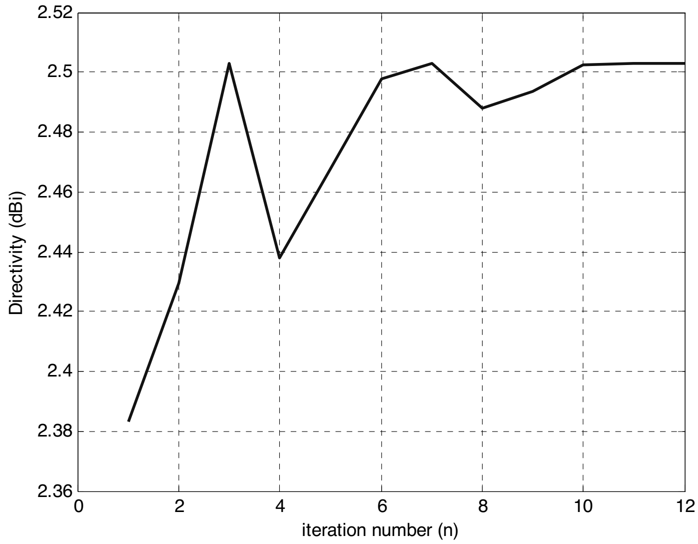

Figure 5. Directivity versus IWO iteration number for a linear array.

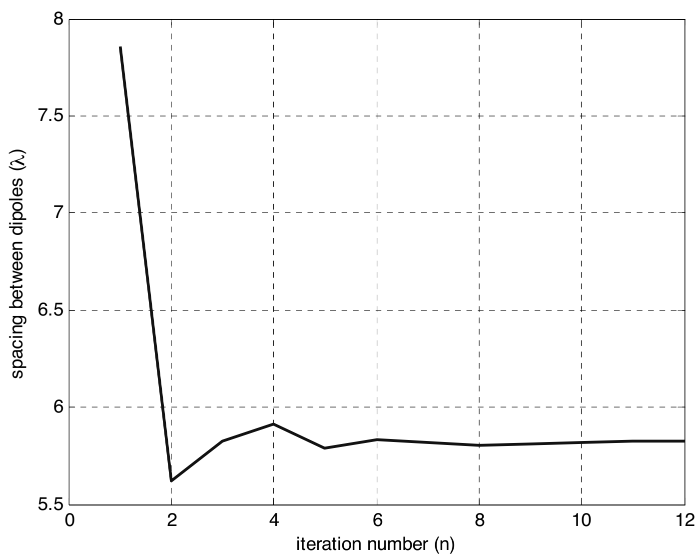

Figure 6. Dipole spacing in linear array versus IWO iteration number.

Table 2. IWO parameters values for configuration 2.

Symbol	Quantity	Value
No	Number of initial population	5
$it_{\max}$	Maximum number of iterations	100
dim	Problems dimension	1
$P_{\max}$	Maximum number of plant population	5
$S_{\max}$	Maximum number of seeds	25
$S_{\min}$	Minimum number of seeds	0
n	Nonlinear modulation index	3
$\sigma_{initial}$	Initial value of standard deviation	2
σ_{final}	Final value of standard deviation	0.01
d_{ini}	Initial search area	5λ to 15λ

3.3. Configuration 3: Maximization of the Broadside Directivity of a Vee Dipole Antenna [16, 17]

The main parameters involved in the design of a Vee dipole antenna are the length of the wires and the inner angle of the antenna. Fig. 7 shows the geometry of the Vee antenna considered with total length $L = 2L_{arm} + 2L_{feed}$ and inner angle 2α. The directivity of the antenna is maximized at $\theta = \pi/2$. The angle α and total length varies from 10 degree to 90 degree and 0.5λ to 1.5λ, respectively. IWO parameters which are used for optimization of configuration 3 are shown in Table 3. Directivity variations of Vee dipole antenna versus number of iteration are shown in Fig. 8. Directivity variations versus length and angle α for each iteration are shown in Fig. 9. As shown in these figures the optimized value of directivity is 5.8 dBi which corresponds to the length of 1.5λ and $\alpha = 48$. The same results are obtained by Particle Swarm Optimization (PSO). The run time for IWO and PSO are 106 seconds and 158 seconds, respectively.

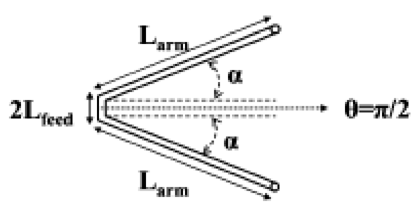

Figure 7. Vee dipole antenna geometry [13].

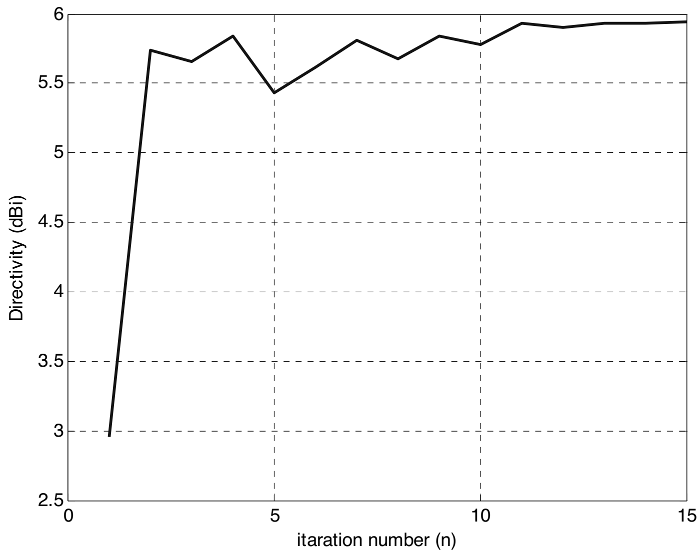

Figure 8. Directivity variations versus iteration number for Vee dipole.

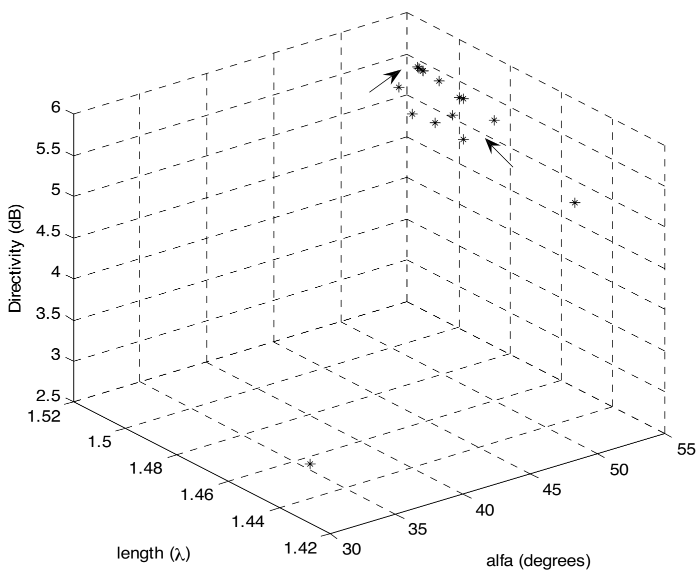

Figure 9. Directivity variations versus length and angle α.

Table 3. IWO parameters values for configuration 3.

Symbol	Quantity	Value
No	Number of initial population	5
$it_{\max}$	Maximum number of iterations	100
dim	Problem dimension	2
$P_{\max}$	Maximum number of plant population	5
$S_{\max}$	Maximum number of seeds	25
$S_{\min}$	Minimum number of seeds	0
n	Nonlinear modulation index	3
$\sigma_{initial}$	Initial value of standard deviation	2
σ_{final}	Final value of standard deviation	0.01
L_{ini}	Initial search area	0.5λ to 1.5λ
α_{ini}		10 to 90 degree

3.4. Configuration 4: Maximization of the Directivity of Collinear Array antennas comprising Half-wavelength Dipoles [15]

A collinear array of uniformly excited half-wavelength dipoles helps to provide an example of antenna optimization for which the solution is independent of the dimension of the search space. The geometry consists of N half-wavelength dipoles aligned along the Z-axis; the positions vary along that axis. The term d_i refers to the varying distance between the center of the ith and the $(i+1)$th dipole, $i = 1, \ldots, N-1$ (Fig. 10). Each d_i varies from 0.5λ to 1.5λ. In order to optimize this geometry we consider a particular case, wherein the number of array dipoles is 13 and the spacing between elements is the same. The directivity of this configuration is computed at $\theta = \pi/2$. IWO parameters which are used for optimization of configuration 4 are

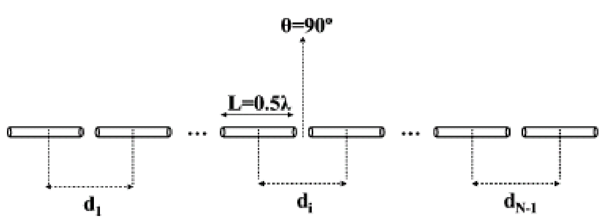

Figure 10. Collinear array of N half-wavelength dipoles [13].

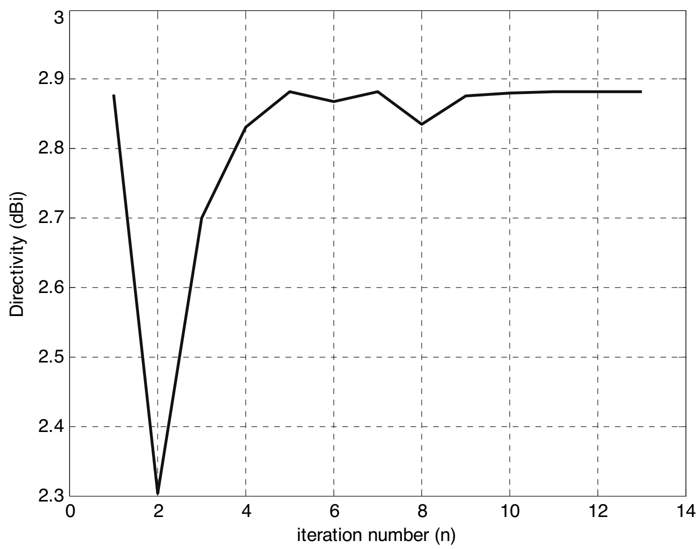

Figure 11. Directivity variations versus iteration number for collinear array.

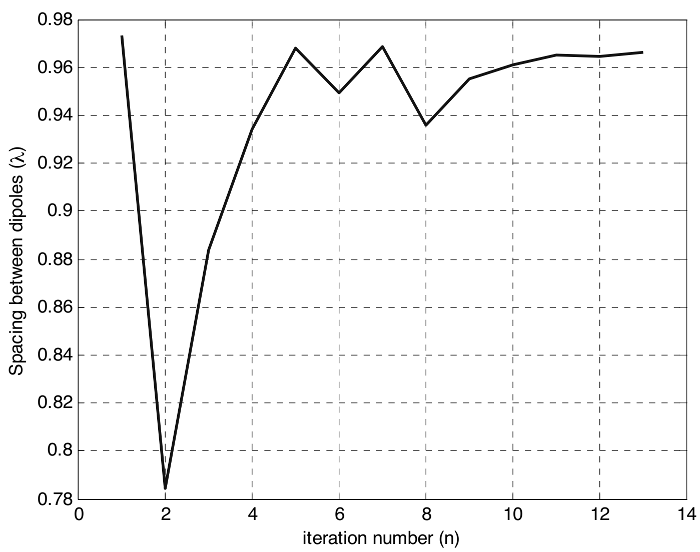

Figure 12. Dipole spacing in collinear array versus IWO iteration number.

Table 4. IWO parameters values for configuration 4.

Symbol	**Quantity**	**Value**
No	Number of initial population	5
$it_{\max}$	Maximum number of iterations	100
Dim	Problem dimension	1
$P_{\max}$	Maximum number of plant population	5
$S_{\max}$	Maximum number of seeds	25
$S_{\min}$	Minimum number of seeds	0
N	Nonlinear modulation index	3
$\sigma_{initial}$	Initial value of standard deviation	2
σ_{final}	Final value of standard deviation	0.01
d_{ini}	Initial search area	0.5λ to 1.5λ

shown in Table 4. Spacing and directivity variations of the collinear array dipole antenna versus number of iterations are depicted in Figs. 11 and 12, respectively, showing the optimized value of directivity is 2.9 dBi which corresponds to the spacing of 0.97λ. Again the same results are obtained by Particle Swarm Optimization (PSO). The IWO and PSO take 82 seconds and 55 seconds, respectively.

4. CONCLUSION

In this paper, the colonizing weeds (IWO) algorithm proposed in [12], is applied to the concept of optimizing antenna structures. Moreover, the effectiveness of the proposed algorithm is examined in various antenna configurations. Simulation results show that there is a good agreement between the results obtained by the proposed method and the PSO algorithm. The proposed method introduces the accuracy as well as convergence speed and simplicity.

REFERENCES

1. Rahmat-Samii, Y. and E. Michielssen, *Electromagnetic Optimization by Genetic Algorithms*, Wiley, 1999.
2. Lu, Y. Q. and J. Y. Li, "Optimization of broadband top-load antenna using micro-genetic algorithm," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 6, 793–801, 2006.

3. Mahanti, G. K., N. Pathak, and P. Mahanti, "Synthesis of thinned linear antenna arrays with fixed sidelobe level using real-coded genetic algorithm," *Progress In Electromagnetics Research*, PIER 75, 319–328, 2007.
4. Mahanti, G. K., A. Chakrabarty, and S. Das, "Phase-only and amplitude-phase only synthesis of dual-beam pattern linear antenna arrays using floating-point genetic algorithms," *Progress In Electromagnetics Research*, PIER 68, 247–259, 2007.
5. Sijher, T. S. and A. A. Kishk, "Antenna modeling by infinitesimal dipoles using genetic algorithms," *Progress In Electromagnetics Research*, PIER 52, 225–254, 2005.
6. Robinson, J. and Y. Rahmat-Samii, "Particle swarm optimization in electromagnetics," *IEEE Trans. Antennas Propag.*, Vol. 52, 397–407, 2004.
7. Lee, K. C. and J. Y. Jhang, "Application of particle swarm algorithm to the optimization of unequally spaced antenna arrays," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 14, 2001–2012, 2006.
8. Chen, T. B., Y. L. Dong, Y.-C. Jiao, and F.-S. Zhang, "Synthesizes of circular antenna array using crossed particle swarm optimization algorithm," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 13, 1785–1795, 2006.
9. Boeringer, D. and D. Werner, "Particle swarm optimization versus genetic algorithms for phased array synthesis," *IEEE Trans. Antennas Propag.*, Vol. 52, 771–779, 2004.
10. Karaboga, N., K. Guney, and A. Akdagli, "Null steering of linear antenna arrays with use of modified touring ant-colony optimization algorithm," *Wiley Periodicals*, 375–383, 2002.
11. Coleman, C., E. Rothwell, and J. Ross, "Investigation of simulated annealing, ant-colony optimization, and genetic algorithms for self-structuring antennas," *IEEE Trans. Antennas Propag.*, Vol. 52, 1007–1014, Apr. 2004.
12. Mehrabian, A. R. and C. Lucas, "A novel numerical optimization algorithm inspired from weed colonization," *Ecological Informatics*, Vol. 1, 355–366, 2006.
13. Pantoja, M. F., A. R. Bretones, and R. G. Martin, "Benchmark antenna problems for evolutionary optimization algorithms," *IEEE Trans. Antennas Propag.*, Vol. 55, 1111–1121, Apr. 2007.
14. Balanis, C. A., *Antenna Theory. Analysis and Design*, Wiley, 1997.
15. Hansen, R. C., *Phased Array Antennas*, Wiley, 1998.

16. Collin, R. E., *Antennas and Radiowave Propagation*, McGraw Hill, 1985.
17. Martín, R. G., A. R. Bretones, and M. F. Pantoja, "Radiation characteristic of thin-wire V-antennas excited by arbitrary time dependent currents," *IEEE Trans. Antennas Propag.*, Vol. 49, 1877–1880, Dec. 2001.