Spider Monkey Optimization: A Novel Technique for Antenna Optimization

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Spider Monkey Optimization: A Novel Technique for Antenna Optimization

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***Abstract*— The aim of this paper is to introduce and use the spider monkey optimization (SMO) as an optimization technique for the electromagnetics and antenna community. The SMO is a new swarm intelligence technique which models the foraging behavior of spider monkeys. To show the efficiency of the SMO, different examples are presented and the results are compared with the results obtained using other popular optimization techniques. The optimization procedure is used to synthesis the array factor of a linear antenna array and to optimally design an E-shaped patch antenna for wireless applications. By comparing to traditional optimization techniques that reported in the literature, it is evident that SMO is efficient in reaching the optimum solutions with less number of experiments.**

***Index Terms*— Array antennas, optimization methods, microstrip antenna, spider monkey algorithm.**

I. INTRODUCTION

Generally, optimization methods can be divided into two categories: deterministic and meta-heuristic methods. Among the most known deterministic methods: the quadratic programming, the Newton method, the Simplex method, and the gradient method. Many drawbacks are associated with using deterministic methods such as needing a good starting point, trapping in local optima, and requiring too much time to resolve complex optimization problems.

On the other hand, meta-heuristics are a family of stochastic algorithms. The adaptation to a wide range of problems without major changes in their algorithms is considered the main advantage of such optimization methods. Since the early 1970s, different meta-heuristic optimization methods have been introduced in the literature. Many of these search techniques are inspired by natural `laws and biological swarm intelligence. The most familiar optimization techniques are: Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and Simulated Annealing (SA).

Many studies have been used the meta-heuristics optimization schemes to solve electromagnetic problems such the ones that reported in [1-3]. The reported results show the efficiency and flexibility of such techniques in solving complex problems.

The spider monkey optimization algorithm (SMO), which is not well known to the electromagnetic community, will be presented in this paper. The main goal of this paper is to introduce the SMO method and to demonstrate its effectiveness to allow this algorithm to join other popular evolutionary optimization techniques as a useful tool for electromagnetic problems. SMO was developed by Bansal et al. in 2014 [4] and its principle is based on modeling the foraging behavior of spider monkeys.

In this paper, two design examples have been chosen to show the possibilities of the SMO algorithm. The first example is a synthesis of the radiation pattern of a symmetric linear array antenna of *2N* elements with sidelobe level suppression and null control in specified directions. However, the algorithm can be used for synthesis of any other array configuration such as: planar, circular, and concentric circular arrays. In the second example, SMO is combined with a numerical solver to optimally design an E-shaped microstrip patch antenna for wireless communication. We employ the CST STUDIO which is a commercially EM solver as a numerical solver. The results obtained in this paper show that the SMO method is straightforward and simple to implement with quick convergence to the optimum designs compared to the most familiar optimization techniques like PSO, GA, and ACO.

The present paper is organized as follows: SMO method will be briefly described in Section II. Following this, different optimization examples are presented in section III, including a synthesis of linear antenna array and the design of an E-shaped microstrip patch antenna. Final remarks and conclusions are presented in Section IV.

II. SMO ALGORITHM

The SMO optimization method will be briefly described in this section. More details for the interested reader can be found in [4].

SMO is inspired by the foraging behavior of spider monkeys. The solutions of the problem are represented by food sources of spider monkeys. According to the calculated fitness value, the superiority of a food source will be decided.

In the SMO algorithm, there are four control parameters: *LocalLeaderLimit*, *GlobalLeaderLimit*, maximum group (*MG*) and perturbation rate (p_r). The *LocalLeaderLimit* is used to

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indicate the point when the group needs to be re-directed to a different direction for foraging if there is no update in the local group leader in a specified number of times. If the *GlobalLeaderLimit* value is reached without any update in global leader, the global leader breaks the group into smaller sub-groups. *MG* and p_r are used to specify the maximum number of groups in the population and to control the amount of perturbation in the current position, respectively.

A flow chart outlining the main steps of the SMO optimization method is given in Fig.1.

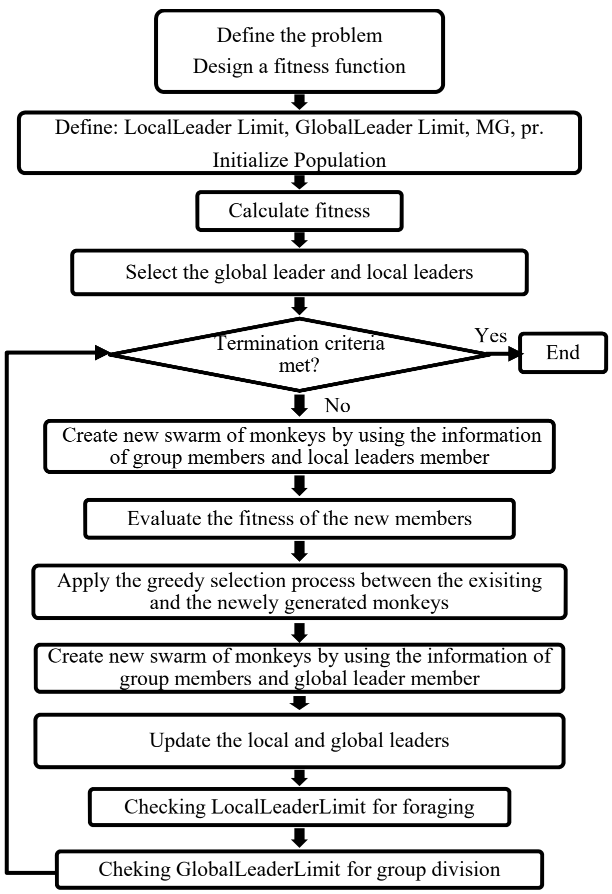

Fig.1 Flow chart of the SMO algorithm.

According to the suggestions in [4], the values of parameters for the SMO algorithm are as follows for all design cases in this paper: maximum number of groups in the swarm (*MG*) = *N/4*, *GobalLeaderLimit* = *N/2*, *LocalLeaderLimit* = *DxN*, and *pr =0.25*. Where *N* is the swarm size and *D* is the number of variables in the optimization problem.

III. DESIGN EXAMPLES

In this section, to demonstrate the versatility and robustness of the SMO algorithm, a linear antenna array synthesis and E-shaped patch antenna design by using the SMO algorithm will be presented.

A. LINEAR ANTENNA ARRAY SYNTHESIS

To demonstrate the possibilities of the algorithm, a linear array of *2N* isotropic elements will be optimally synthesized by using the SMO. Different optimization techniques have been used in designing linear array antennas [5-8]. SMO will be used here for sidelobe level suppression and null control synthesis.

A linear array antenna consisting of *2N* elements placed along the *z*-axis is shown in Fig.2. The excitations of the array elements are considered symmetric about the center of the array.

Owing to the symmetry, the array factor of a linear array antenna with *2N* elements can be written as:

$$AF(\theta) = 2\sum_{n=1}^{N} a_n cos(kz_n \cos(\theta) + \beta_n) \qquad (1)$$

where k is the wave number and a_n, z_n and β_n are the excitation magnitude, position, and phase of the n[th] element, respectively.

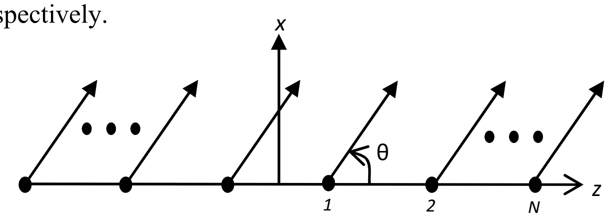

Fig.2 The geometry of a *2N*- element symmetric linear array

As a first design case, sidelobe-level (SLL) synthesis will be shown. A 10-element linear aperiodic array is attempted. For the current problem, SMO is used to optimize the geometry of a linear antenna to achieve a minimum SLL. The same synthesis problem was addressed in [5] using ACO, in [6] using the PSO, and in [7] using the Self-adaptive Hybrid Differential Evolution (SHDE). A uniform amplitude excitation ($a_n=1$) with no phase differences ($\beta_n=0$) is assumed in the array factor calculations for a fair comparison between the SMO and the other mentioned optimization techniques. To evaluate the fitness of each possible solution, the following function is minimized by using SMO:

$$F(\bar{z}) = max\{|AF^{\bar{z}}(\theta)|\} \Big|_{\theta \in S} \qquad (2)$$

where $\bar{z}$ is the vector of the element positions. Excluding the main lobe, S is the space spanned by the angle θ. Excluding the main lobe is done by spanning the scanning angle from θ=0º to θ=78º. The SMO is used to find the optimal locations of the array elements that accomplish the design requirement. With N= 12, D= 5, and after 100 iterations, an optimal array factor is obtained and presented in Fig.3, along with patterns obtained using the ACO, the PSO, and the SHDE. The calculated element positions are given in Table I. The maximum value of SLL obtained by using the SMO is -20.25 dB, which is better than the -18.27 dB by the ACO [5], -17.41 dB by the PSO [6], the -19.71 dB by the SHDE [7]. These results show the capability of SMO to outperform ACO, PSO, and even the more sophisticated SHDE. Moreover, 20 particles and 500 iterations were used in [6] which is indicated that a 88% reduction in the number of function evaluations has been achieved by using the SMO. Also, the number of the SMO function evaluations used to achieve a SLL of -20.25 dB is matching the minimum number of functions evaluations used by the SHDE [7].

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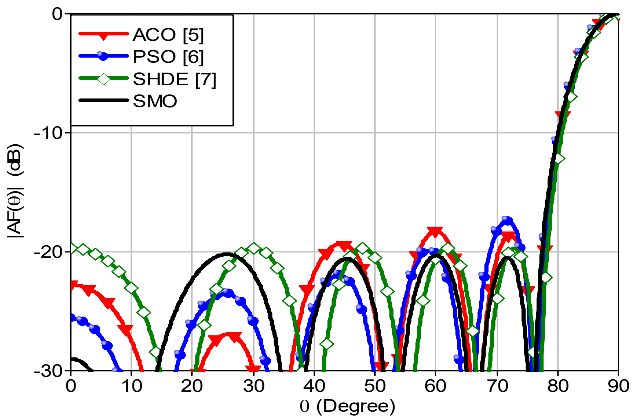

Fig. 3 Array factor comparison between the SMO based, ACO-based [5], the PSO-based [6], and the SHDE-based designs [7].

TABLE I
OPTIMAL ELEMENT POSITIONS FOR THE SYNTHESIZED ARRAY (units: λ).

	1st	*2nd*	*3rd*	*4th*	*5th*
ACO	0.25	0.55	1.05	1.55	2.15
PSO	0.2515	0.555	1.065	1.5	2.11
SHDE	0.215	0.5999	1.061	1.587	2.25
SMO	0.236	0.528	1.007	1.471	2.126

To further validate the efficiency of the SMO method, a wide null beam pattern design with low SLL is presented here. The performance of the SMO is compared with one of the famous meta-heuristic technique which is real-coded GA (RCGA) [9]. RCGA is considered faster than the binary GA, where the variables of problem are represented as real numbers. The excitation magnitudes of array elements is optimized so that the corresponding array factor has nulls at specified directions. A 20-element equally spaced linear array with element spacing of a half-wavelength is used here. A wide null is desired between 50º and 60º, and the desired null level should be lower than -55 dB. Moreover, the SLL should be lower than -20 dB. SMO with *N=20* and *D=10* is used to minimize the following fitness function:

$$F(\bar{a}) = max\{|AF^{\bar{a}}(\theta)|\}|_{\theta\in S} + max\{|AF^{\bar{a}}(\theta)|\}\,|_{\theta\in U} \quad (3)$$

where $\bar{a}$ is the vector of the element amplitudes and U is the spatial region of the null. Both algorithms are executed 20 times and the best results are compared. For the real-coded GA, the rate of uniform mutation was set to 0.1 and the single crossover was used. For fair comparison, the population size of the GA was set equal to 20. The number of iterations was set equal to 500 and random values are used to initialize both algorithms. An optimal null control pattern is obtained and presented in Fig.4 along with the one obtained by using the GA. The optimized excitation magnitudes of the elements obtained by using SMO from number one to number ten are [0.772, 0.771, 0.773, 0.645, 0.496, 0.505, 0.368, 0.461, 0.199, 0.166]. The result shows that the depth of the wide null is below -55 dB and the sidelobe level is below -20 dB as desired. The average cost function convergence rate over 20 trials is given in Fig.5. It is obvious that for this design example that SMO outperforms GA.

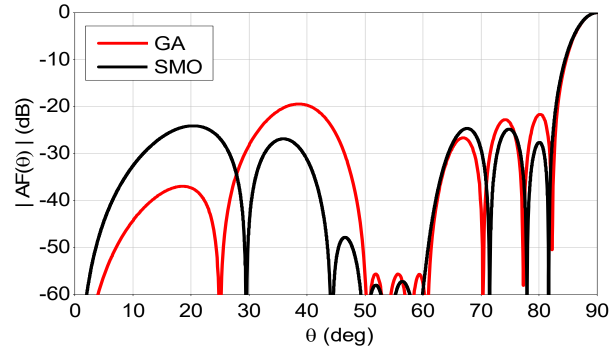

Fig. 4 Null controlled pattern of an optimized 20-element linear array antenna.

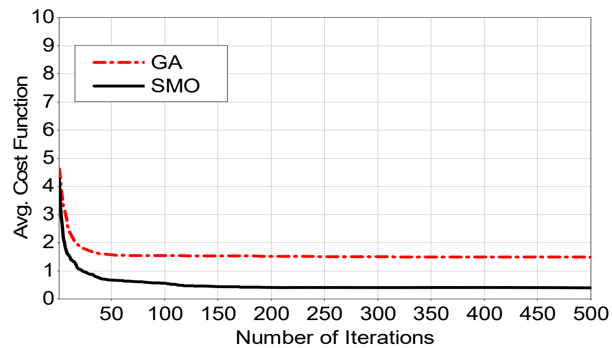

Fig. 5 Convergence rate plot for the 20-element array case.

B. APPLYING SMO TO ANTENNA DESIGN FOR WIRELESS COMMUNICATION SYSTEMS

An E-shaped microstrip antenna as shown in Fig. 6 is used as an example to demonstrate the validity of the SMO method in antenna design. The same problem was optimized by the wind driven optimization (WDO) [8], the differential evolution (DE) and the self-adaptive differential evolution (SADE) [10]. The SMO optimization engine with an EM simulator is applied to find the optimized design. The full 3D electromagnetic simulation software CST STUDIO SUITE is linked to the optimization program for computing antenna performance characteristics as it is illustrated in Fig.7. As shown in Fig.6, a rectangular patch is centered at the middle of a 60 x 60 mm^2 ground plane, with an air substrate of 5.5 mm thickness. Two identical symmetrical slots are inserted into radiating edge of the patch. The dimension of the slots is Ws × Ls. The slots are centered at a distance of Ps from the feed position. In this application, six parameters are to be optimized for the best impedance match. Table II enlists all the parameters for the SMO optimizer. Many design bounds are introduced to maintain the E-shape of the antenna [11].

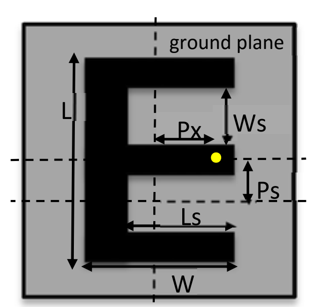

Fig. 6 E-shaped patch antenna geometry.

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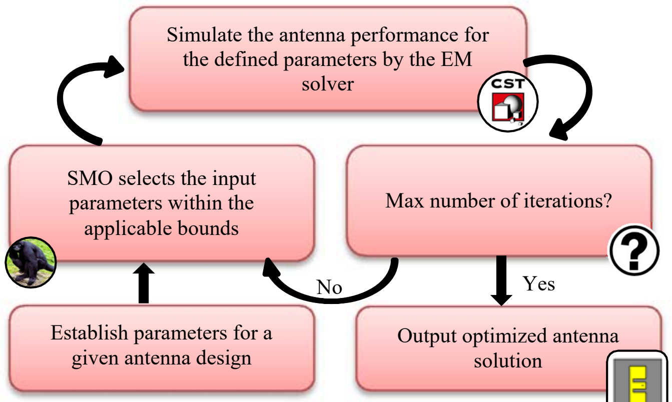

Fig. 7 The SMO implementation strategy with commercial EM solvers.

The objective function for the antenna is calculated by using the following equation:

$$F(\bar{x}) = maximize\left[min\left\{\left|S_{11}(\bar{x})\right|_{f=5\ GHz}\right|, \left|S_{11}(\bar{x})\right|_{f=5.5\ GHz}\right|\right\}\right] \quad (4)$$

where $\bar{x}$ is the design variable vector and S_{11} is the reflection coefficient in decibels at the given frequency. With a population size of 20 spider monkeys and D= 6, SMO is allowed to run for 50 iterations. Table III shows the optimized values for selected antenna parameters.

TABLE II
SUMMARY OF THE ANTENNA OPTIMIZATION

Optimization parameters	*W, L, Ws, Ls, Ps, Px*
Swarm size	*20*
Max iterations	*50*
Design bounds	*10<W<50, 10<L<30, 0.5<Ws< (W/2), 0.5<Ls<L, (Ws/2)<Ps<(W/2)-(Ws/2), |Px|<(L/2)*

The return loss of the optimized configuration is shown in Fig.8, and good impedance matching ($S_{11} < -30$ dB) at the two specified frequencies is obtained. Table IV shows that the S_{11} values of -37 dB or lower are achieved at 5.0 GHz and 5.5 GHz, outperforming the performance of the WDO, the DE, and even the more sophisticated version of DE, SADE [8, 10].

TABLE III
THE DIMENSIONS OF THE OPTIMIZED E-PATCH ANTENNA (IN MILLIMETERS)

L	W	Px	Ls	Ws	Ps
21.05	43.11	6.22	16.49	3.54	5.64

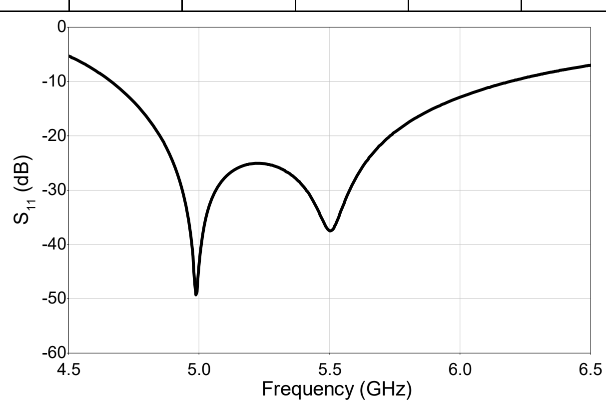

Fig. 8. The optimized response of the E-shaped antenna.

TABLE IV
PERFORMANCE OF WDO, DE, SADE, AND SMO IN OPTIMIZING THE E-SHAPE PATCH ANTENNA

	WDO [8]	DE[10]	SADE[10]	SMO
MAX{ S_{11}}	-31	-30.48	-34.06	-37

IV. CONCLUSION

In this paper, the Spider Monkey Optimization (SMO) method was introduced for the first time for solving electromagnetic problems. The SMO method was used in the synthesis of linear array antenna for the purpose of suppressed sidelobes and null placement in certain directions. Moreover, the SMO had been linked to full 3D electromagnetic simulation software to find the optimal dimension of an E-shaped patch antenna. A performance comparison of the SMO algorithm with the other well-known techniques had been illustrated. Since the SMO method is easy to implement and quick to converge to the optimal solutions, the SMO method will be an increasingly attractive alternative to other evolutionary algorithms such as genetic algorithms and particle swarm in the electromagnetics and antennas community.

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