Spider Monkey Optimization (SMO): A Novel Optimization Technique in Electromagnetics

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***Abstract* — Introducing and using the spider monkey optimization (SMO) as an optimization technique for the electromagnetics and antenna community is the main goal of this paper. 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 in this work. The optimization procedure is used to synthesize the array factor of a linear antenna array and to optimally design a coaxial feeding patch antenna for wireless applications. The obtained results show that SMO is efficient in reaching the optimum solutions with few number of experiments.**

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

I. Introduction

Optimization is the process of adjusting a set of input parameters to characterize a mathematical process, or an experiment with the objective to find the minimum or maximum desired output quantities. Optimization methods can be divided into two categories: deterministic and stochastic methods. The quadratic programming, the Newton method, and the gradient method are considered the most known deterministic methods. Needing a good starting point, trapping in local optima, and requiring too much time to resolve complex optimization problems are the main drawbacks of these techniques.

On the other hand, different stochastic optimization methods have been introduced in the last few years. 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). The adaptation to a wide range of problems without major changes in their algorithms is considered the main advantage of such optimization methods. Many studies have been used the stochastic optimization schemes to solve electromagnetic problems such the ones that reported in [1-5]. 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 [6] and its principle is based on modeling the foraging behavior of spider monkeys.

II. SMO ALGORITHM

SMO is inspired from 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.

The SMO includes six phases. In the first two phases, the spider monkeys are updating their positions according to the experience of the local and global leaders and also the experience of the local group members. The greedy selection is used in the global and local leaders learning phases to update the positions of the global and local leaders according to the fitness values. In the last two phases and after a predetermined number of iterations, decisions will be made either to update the position of the all group members or divide the population into smaller groups. More details for the interested reader can be found in [6].

There are four main control parameters in the SMO algorithm: LocalLeaderLimit, GlobalLeaderLimit, maximum group (MG) and perturbation rate (pr). The LocalLeaderLimit is used to 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 Pr 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 steps in the SMO optimization method is given in Fig.1.

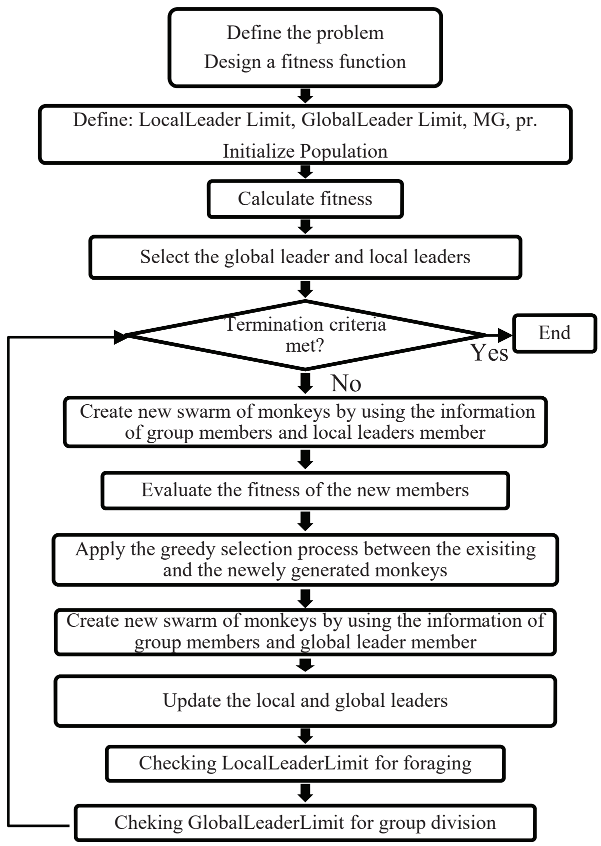

Fig.1 Flow chart of the SMO algorithm.

As suggested in [6], the following values for the control parameters will be used:

- MG = N/10,
- GlobalLeaderLimit ∈ [N/2, 2 × N]
- LocalLeader Limit = D × N
- Pr ∈ [0.1, 0.9]

where N is the swarm size and D is the number of variables in the optimization problem. For all design cases in this paper, the values of parameters for the SMO algorithm are as follows: swarm size (S) =20, maximum number of groups in the swarm (MG) = 10, global leader limit =10, local leader limit =D*N, and perturbation rate (Pr)= 0.25.

III. DESIGN EXAMPLES

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

A. Synthesis of Linear Array Antenna

A linear antenna array optimization is used as an example in this paper to illustrate the implementation procedure of the SMO algorithm. Fig.2 shows a linear array antenna consisting of 20 elements placed along the z-axis. The excitations of the array elements are considered symmetric about the center of the array.

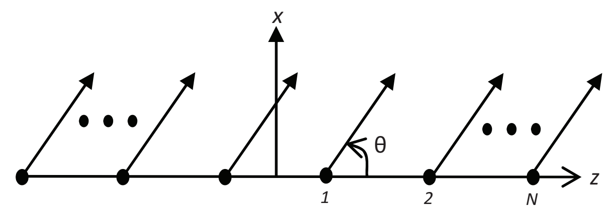

Fig. 2. The geometry of a 2N- element symmetric linear array

The array factor of a symmetric linear array antenna with 2N elements can be written as:

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

where k is the wave number and I_n, z_n and φ_n are the excitation magnitude, position, and phase of the n^{th} element, respectively.

A 20-element linear array equally spaced linear array with element spacing of a half-wavelength is used here. SMO is used to optimize the excitations magnitude of a linear antenna to achieve a minimum sidelobe level (SLL). If G is the cost function that needs to minimize by using SMO, then it can be written as follows:

$$G(\bar{I}) = max\{AF_{dB}^{\bar{I}}(\theta)\} \Big|_{\theta\in S} \qquad (2)$$

where $\bar{I}$ is the vector of the element excitations. Excluding the main lobe, S is the space spanned by the angle θ. After 500 iterations with size of 20 spider monkeys, an optimal pattern is obtained and presented in Fig.3. The optimized elements excitation from number one to number ten are [0.3982, 0.3002, 0.4046, 0.28, 0.2977, 0.3115, 0.2117, 0.1886, 0.2402, 0.2536]. The result shows that the sidelobe level is below -20.47 dB which is lower than the uniform distribution case by 7.28 dB.

B. Applying SMO to Antenna Design for Wireless Communication Systems

To demonstrate the validity of the SMO method in antenna design, the SMO optimization engine with an EM simulator is applied here to find the optimized design of a coaxial feeding microstrip antenna. The full 3D electromagnetic simulation software CST STUDIO SUITE is linked to the optimization program for computing antenna performance characteristics. As shown in Fig. 4, 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. In this application, the width (W) and length (L) of the patch in addition to the feeding position (Px) are to be optimized by using the SMO method for the best impedance match.

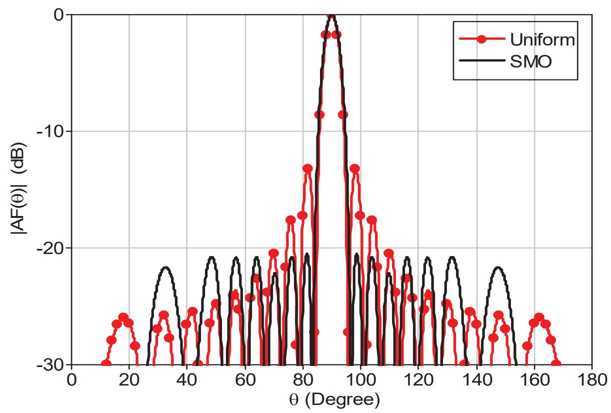

Fig. 3 Array factor comparison.

The objective function for the antenna that will be maximized by the SMO is calculated by using the following equation:

$$G(\bar{x}) = \left|S_{11}(\bar{x})|_{f=5.5\,GHz}\right| \tag{3}$$

where $\bar{x}$ is the design variable vector and S_{11} is the reflection coefficient in dB at the given frequency. After only 50 iteration with swarm size of 20 spider monkeys, optimal response is obtained with reflection coefficient of about -70 dB at the desired frequency as shown in Fig.5. The optimized variables obtained by the SMO are as following: L=24.5 mm, W=14.84 mm, and Px=8.66 mm.

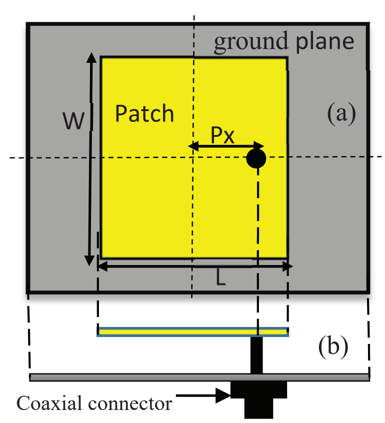

Fig. 4. Patch antenna geometry: (a) Top view (b) Side view

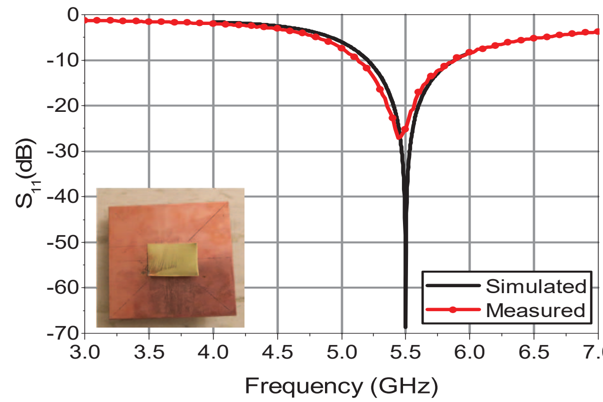

Fig. 5. The optimized response of the patch antenna.

IV. CONCLUSION

Spider monkey optimization method, which is a new meta-heuristic optimization technique, has been presented in this paper for solving electromagnetic problems such linear array antenna synthesis and patch antenna design. According to the obtained optimization results in addition to the quick convergence to the desired goals, SMO is considered a good candidate for optimizing various electromagnetic applications and might extend to different areas of antenna design. For future work, the performance of the SMO will be compared with the performance of the most familiar meta-heuristic methods like GA, PSO, and ACO.

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