Design of Linear Antenna Arrays Using Antlion and Grasshopper Optimization Algorithms

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***Abstract*— The design of linear antenna arrays is one of the important electromagnetic optimization problems. In this paper, the problem of designing these arrays for specific radiation properties is dealt with. The Antlion optimization (ALO) and Grasshopper optimization algorithm (GOA) methods, which represent new evolutionary algorithms, are used in the optimization process. ALO and GOA are used to minimize the maximum side lobe level (SLL) by optimizing the excitation current amplitudes of array elements. The results obtained show the effectiveness of ALO and GOA compared to other optimization methods.**

***Keywords*—Antenna arrays; linear arrays; optimization methods; Antlion optimization (ALO); Grasshopper optimization algorithm (GOA)**

I. INTRODUCTION

Antenna is a key part of any electronic system which transmits or receives electromagnetic energy or signal in a wireless way. It is widely used in satellite, mobile and radar systems [1]. Antenna array is formed using intelligent combination of various antenna elements for better directivity and half power beam width along with significant reduction in side lobe level (SLL). Side lobe level is an important metric used in antenna array that depends upon the elements excitations and their positions in the antenna array [2]. Compared to a single antenna, the main advantage of an antenna array is that the performance can be easily modified based on the radiation pattern without mechanical and structural changes [3].

Several evolutionary optimization techniques; such as ant colony optimization [4], particle swarm optimization (PSO) [5,6], Taguchi optimization [7], invasive weed optimization [8], pattern search optimization [9], biogeography based optimization (BBO) [10], firefly algorithms (FA) [11], and cat swarm optimization [12]; have been successfully applied in designing linear antenna array.

The purpose of this paper is to use Antlion Optimization (ALO) and Grasshopper Optimization Algorithm (GOA) for optimization of linear antenna arrays to achieve a desired fitness function. The Ant lion optimization technique (ALO) mimics the behavior of antlion in hunting other insects [13] and Grasshopper optimization technique (GOA) works on the behavior of grasshopper's swarm and their tendency to food resources [14]. This paper also presents performance comparison of ALO and GOA with other optimization techniques such as Particle swarm optimization (PSO), Biography-based optimization (BBO) and Taguchi algorithm [15] for optimization of linear antenna array. The nature inspired optimization techniques (ALO and GOA) work nicely over previous techniques to get reduced SLL.

The rest of this paper is organized as follows: In Section II, ALO and GOA algorithms are presented. In Section III, the geometry and array factor for the linear antenna arrays (LAA) is presented. Then, the fitness function is presented in section IV. Moreover, numerical results are given and compared to the results obtained using other optimization methods. Finally, the paper is concluded in Section V.

II. ANTLION AND GRASSHOPPER OPTIMIZATION TECHNIQUES

A. *Antlion Optimization Technique [13]*

Antlions (doodlebugs) belong to the Myrmeleontidae family and Neuroptera order. The lifecycle of antlions includes two main phases: larvae and adult. They mostly hunt in larvae and the adulthood period is for reproduction. The main inspiration of the ALO algorithm, originally proposed by Seyedali Mirjalili in 2015, comes from the foraging behavior of ant lion's larvae.

An antlion larva digs a cone-shaped pit in sand by moving along a circular path and throwing out sands with its massive jaw. After digging the trap, the larva hides underneath the bottom of the cone. Once the antlion realizes that a prey is in the trap, it tries to catch it. However, insects usually try to escape from the trap. In this case, antlions intelligently throw sands towards to edge of the pit to slide the prey into the bottom of the pit. When a prey is caught into the jaw, it is pulled under the soil and consumed. After consuming the prey, antlions amend the pit for the next hunt [13]. Figure 1 shows the cone-shaped traps and hunting behavior of antlions. So, ALO mimics the hunting mechanism between ant lions and insects (preferably ants) inside the trap.

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Recently, ALO has been applied successfully in other fields, like the hybrid power generation systems (HPGS) [16], optimal power flow [17], the preventive maintenance scheduling of generating units under reliability criterion [18] and Load Balancing problems [19].

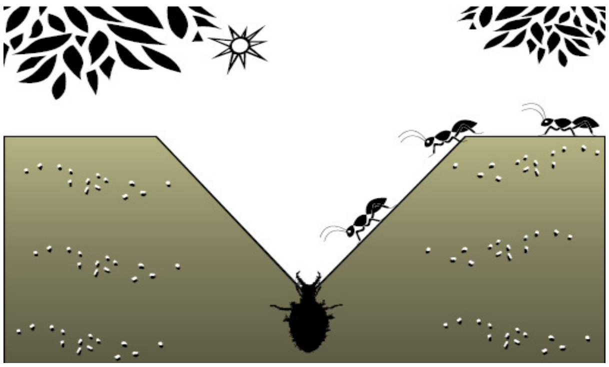

Figure 1: The cone-shaped traps and hunting behavior of antlions [13].

B. Grasshopper Optimization Algorithm [14]

Grasshoppers are insects. They are considered pests due to their damage to crop production and agriculture. Grasshoppers are usually seen individually in nature, but sometimes they join in one of the largest swarm of all creatures. Millions of nymph grasshoppers jump and move like rolling cylinders. After this behavior, when they become adults, they form a swarm in the air. This is how grasshoppers migrate over large distances. Food source seeking is an important characteristic of the swarming of grasshoppers [14].

The GOA mimics the behavior of grasshopper swarms in nature and their tendency for seeking the food sources to solve optimization problems. So, GOA studies the social forces between adjacent grasshoppers and links this force with deciding the next position of the grasshopper.

To our knowledge, GOA has not been applied in Electromagnetics before.

For brevity purposes, the details of ALO and GOA will not be presented here; the interested reader can consult the references cited above for the full details of the algorithms.

III. GEOMETRY AND ARRAY FACTOR OF LINEAR ANTENNA ARRAY

The linear array is one of the commonly used arrays in many applications owing to its simplicity [11]. The representation of such geometry is shown in Figure 2.

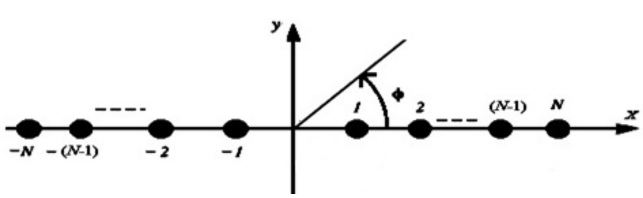

Figure 2: Geometry of the 2N element symmetric linear array.

The array factor of such a linear array with even number of elements can be written as follows [11]:

$$AF(\emptyset) = \sum_{\substack{n=-N \\ n\neq 0}}^{N} I_n \exp(j[kx_n cos(\emptyset) + \varphi_n]) \quad (1)$$

where k is the wave number (k=2π/λ), and I_n, φ_n, and x_n are, respectively, the excitation amplitude, phase, and location of the n^{th} element.

Assuming that the 2N elements are placed symmetrically along the x-axis simplifies the array factor to become as follows:

$$AF(\emptyset) = 2\sum_{n=1}^{N} I_n \cos[kx_n cos(\emptyset) + \varphi_n] \quad (2)$$

According to this formula, the maximum side lobe level (SLL) can be minimized using ALO and GOA methods by optimizing the amplitudes of the elements (I_n).

IV. FITNESS FUNCTION AND NUMERICAL RESULTS

In order to minimize the maximum side lobe level (SLL), the following fitness function is used [15]:

$$fitness = \max \left\{20\log_{10}\left|\frac{AF(\emptyset)}{AF(\emptyset_o)}\right|\right\}$$

$$\text{Subject to} \quad \emptyset \in [0, \emptyset_{\mathrm{n}}] \quad (3)$$

where $[0, \emptyset_{\mathrm{n}}]$ is the side lobes region, which depends on the number of elements. Here, it is chosen as [0, 76º], [0, 80º] and [0, 83º] for 10, 16 and 24 elements linear antenna array (LAA), respectively.

To optimize the amplitudes in the array factor, $\emptyset_{\mathrm{n}}$ and x_n are fixed to be those corresponding to the uniform array, i.e., $\emptyset_{\mathrm{n}}$= 0 and the spacing between adjacent elements equal to (λ/2). So, the array factor becomes:

$$AF(\emptyset) = 2\sum_{n=1}^{N} I_n \cos[(n-0.5)\,\pi\, cos(\emptyset)] \quad (4)$$

The excitation currents amplitudes are assumed to be within the range [0, 1]. Three cases of linear arrays are optimized; 10, 16, 24 elements using the ALO and GOA techniques.

Example 1: 10-Element LAA

In this example, a LAA of 10 elements has been optimized using GOA, ALO, and the results are compared to those reported in [15]. Table 1 shows the best values (the run that gives the least maximum side lobe level) for optimum amplitudes found by the algorithms. The maximum side lobe levels obtained using the GOA, ALO, BBO, PSO and Taguchi methods are: -25.241 dB, -25.2359 dB, -25.21 dB, -24.62 dB and -24.87 dB, respectively. GOA and ALO results are almost the same as those obtained using BBO.

Table 2 shows the optimum amplitude values found by GOA and ALO.

Table 3 represents the consistency of ALO and GOA algorithms in 20 runs. It shows that the standard deviation in ALO is very small where a standard deviation of 1.9972e-06 was obtained, which shows that ALO is more robust than GOA.

Table 1: Best side lobe level values found by GOA and ALO for the 10-element LAA in comparison with other optimization techniques.

Method	Best SLL (dB)
GOA	-25.2410
ALO	-25.2359
BBO [15]	-25.21
PSO [15]	-24.62
Taguchi [15]	-24.87
Uniform [15]	-12.97

Table 2: Optimum amplitude values found by GOA and ALO for the 10-element LAA.

Method	I_1	I_2	I_3	I_4	I_5
GOA	1.0000	0.89848	0.71893	0.50171	0.3856
ALO	1.0000	0.89849	0.71892	0.5017	0.38561

Table 3: Performance of ALO and GOA algorithms for 10 elements LAA in 20 runs.

Method	ALO	GOA
Best SLL (dB)	-25.2359	-25.2410
Worst SLL (dB)	-25.2359	-25.0985
Mean (dB)	-25.2359	-25.2207
Median (dB)	-25.2359	-25.2284
Standard deviation (SD) (dB)	1.9972e-06	0.0305
Approximate CPU time for each run	90 seconds	440 seconds

Figure 3 shows the radiation pattern obtained by ALO and GOA compared to other methods. It is indicated that GOA and ALO here are slightly better than other algorithms. The convergence curve for the best run of ALO and GOA over 1000 iterations is shown in Figure 4. It can be noticed that 100 iterations only are needed to reach the global minimum for ALO and less than 30 iterations are enough to almost reach the global optimum for this 10-element LAA design problem using GOA.

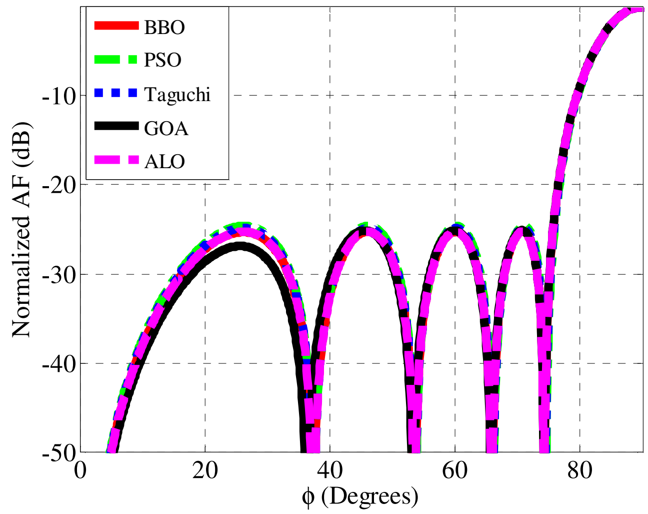

Figure 3: Radiation pattern of ALO and GOA-optimized 10-element LAA compared to other optimization techniques

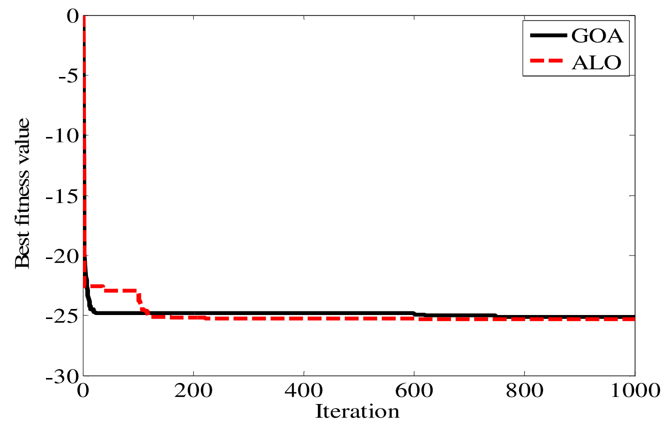

Figure 4: Convergence curve of ALO and GOA-optimized 10 elements LAA over 1000 iterations for the best run.

Example 2: 16-element LAA

In this example, a 16-element LAA is optimized using ALO and GOA methods. The best results of least side lobe level are listed in Table 4. The maximum SLL obtained using ALO and GOA methods are -33.3642 dB and -33.3488 dB, respectively, which are somewhat better than those obtained using BBO, PSO and Taguchi methods.

Table 5 shows the optimum amplitude values found by GOA and ALO. Table 6 represents the consistency of ALO and GOA algorithms in 20 runs.

Table 4: Best side lobe level values found by GOA and ALO for the 16-element LAA in comparison with other optimization techniques.

Method	Best SLL dB
GOA	-33.3488
ALO	-33.3642
BBO [15]	-33.06
PSO [15]	-30.63

Taguchi [15]	-31.2
Uniform [15]	-13.15

Table 5: Optimum amplitude values found by GOA and ALO for the 16-element LAA.

Method	$I_1, I_2, \ldots, I_8$
GOA	1.0000 0.94662 0.84754 0.71359 0.56245 0.40926 0.26985 0.20875
ALO	1.0000 0.94661 0.84752 0.71363 0.56239 0.40932 0.26981 0.20879

Table 6: Performance of ALO and GOA algorithms for 16 elements LAA in 20 runs.

Method	ALO	GOA
Best SLL (dB)	-33.3642	-33.3488
Worst SLL (dB)	-33.2358	-32.7309
Mean (dB)	-33.3349	-33.1060
Median (dB)	-33.3368	-33.1466
Standard deviation (SD) (dB)	0.0295	0.1938
Approximate CPU time for each run	70 seconds	260 seconds

Figure 5 shows the radiation pattern obtained by ALO and GOA compared to other methods. Figure 6 shows the convergence curve of ALO and GOA. From the figure, ALO starts converging with less than 300 iterations to reach the optimum value, while GOA starts converging to optimum value almost at 50 iterations.

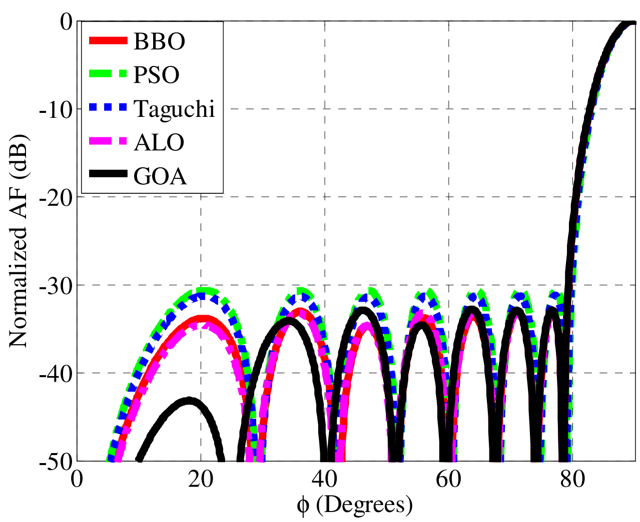

Figure 5: Radiation pattern of ALO and GOA-optimized 16-element LAA compared to other optimization techniques.

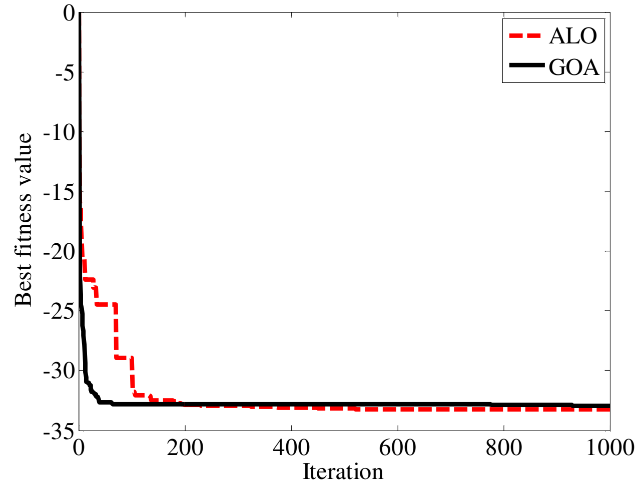

Figure 6: Convergence curve of ALO and GOA-optimized 16 elements LAA over 1000 iterations for the best run.

Example 3: 24-element LAA

The best side lobe level values found by GOA and ALO for the 24-element LAA are tabulated in Table 7. The maximum SLL obtained using the GOA, ALO, BBO, PSO and Taguchi methods are -39.0920 dB, -39.4297 dB, -37.14 dB, -34.46 dB and -35.02 dB, respectively. In this example, it is clearly shown that GOA and ALO outperform BBO, PSO and Taguchi methods.

Table 8 shows the optimum amplitude values found by GOA and ALO for 24 elements LAA. Table 9 displays the consistency of ALO and GOA algorithms.

Table 7: Best side lobe level values found by GOA and ALO for the 24-element LAA in comparison with other optimization techniques.

Method	Best SLL (dB)
GOA	-39.0920
ALO	-39.4297
BBO [15]	-37.14
PSO [15]	-34.46
Taguchi [15]	-35.02
Uniform [15]	-13.22

Table 8: Optimum amplitude values found by GOA and ALO for the 24-element LAA.

Method	$I_1, I_2, \ldots, I_{12}$

GOA	1.0000 0.96223 0.91257 0.83306 0.74453 0.62839 0.52603 0.40036 0.32313 0.22063 0.15064 0.11177
ALO	1.0000 0.97181 0.91445 0.8379 0.7436 0.63711 0.52674 0.41527 0.31534 0.22373 0.15192 0.12372

Table 9: Performance of ALO and GOA algorithms for 24 elements LAA in 20 runs.

Method	ALO	GOA
Best SLL (dB)	-39.4297	-39.0920
Worst SLL (dB)	-39.1616	-33.2048
Mean (dB)	-39.3218	-37.4726
Median (dB)	-39.3495	-38.3924
Standard deviation (SD) (dB)	0.0764	1.8867
Approximate CPU time for each run	100 seconds	740 seconds

The radiation pattern obtained by ALO and GOA compared to other methods is shown in Figure 7 where ALO and GOA have the best ability for minimization compared with other algorithms. The convergence curve for the best run of GOA and ALO is shown in Figure 8.

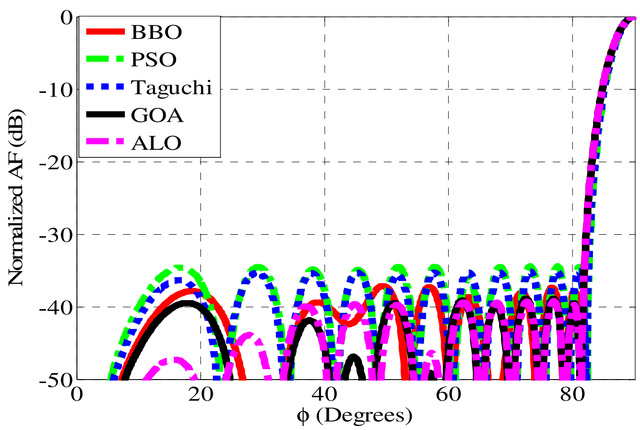

Figure 7: Radiation pattern of ALO and GOA-optimized 24-element LAA compared to other optimization techniques.

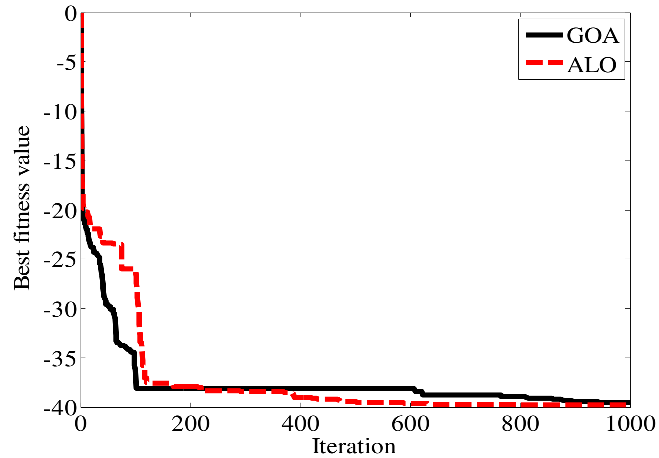

Figure 8: Convergence curve of ALO and GOA-optimized 24 elements LAA over 1000 iterations for the best run.

V. CONCLUSIONS

ALO and GOA were applied on the optimization of linear antenna arrays. The excitation current amplitude has been optimized using three examples; 10, 16 and 24 elements of linear antenna arrays. ALO and GOA results have been compared to well-known optimization techniques (Taguchi, PSO and BBO) where it was found that both algorithms are very good and their results are as good as other methods. It has been found that the standard deviation obtained using ALO and GOA is less than the one obtained by BBO and other optimization techniques. ALO and GOA may be implemented in so many different applications in electromagnetics. Specifically, they will be used in the synthesis of other different configurations of antenna arrays (circular and elliptical) with specific characteristics.

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