GSJ: Volume 12, Issue 1, January 2024, Online: ISSN 2320-9186
www.globalscientificjournal.com

Reduction of Sidelobe Level in Antenna Array for Improved Antenna Performance Using Invasive Weed Optimization

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Abstract:

In this paper, the possibility of minimizing antenna sidelobe level was investigated by using invasive weed optimization (IWO) technique. IWO algorithm which inspired by the dynamics of invasive weed growth, has shown promise in finding global optima in complex, multi-dimensional spaces, and it was used in this work to bring down sidelobe level in antenna array. The effectiveness of the invasive weed optimization algorithm in minimizing the level of sidelobe in antenna array was clearly seen in the comparative examination of the algorithm with two other algorithms such as the biogeography-based optimization (BBO) algorithm and the particle swamp optimization (PSO), where it was shown that of all the three algorithms, invasive weed optimization algorithm had the lowest sidelobe. Besides this good result, it was also observed that IWO was better than PSO and BBO in terms of stability.

Keywords: Antenna Array, Array Factor, BBO, IWO, PSO, Population, Sidelobe

I. Introduction

In the realm of wireless communication and signal processing, optimizing antenna performance is a critical endeavor. The reduction of sidelobe level in antenna arrays has emerged as a key area of focus, aiming to enhance the overall efficiency and reliability of communication systems. Among the myriad optimization techniques, the Invasive Weed Optimization (IWO) algorithm has gained prominence for its ability to efficiently tackle complex problems. This paper delves into the intriguing intersection of these two domains, exploring how IWO can be harnessed to achieve significant improvements in sidelobe reduction, thereby elevating the performance of antenna arrays.

Antenna sidelobes, unwanted lobes of radiation that accompany the main lobe, can introduce interference and degrade the quality of communication signals [1]. Mitigating these sidelobes has become imperative for applications ranging from radar systems to satellite communication. Traditional methods often face challenges in achieving optimal solutions, leading researchers to explore nature-inspired algorithms for more effective optimization. In this context, the Invasive Weed Optimization algorithm, inspired by the dynamics of invasive weed growth, has shown promise in finding global optima in complex, multi-dimensional spaces. The synergy between the reduction of sidelobe level in antenna arrays and Invasive Weed Optimization lies in the algorithm's ability to mimic the invasive behavior of weeds, effectively exploring the solution space and adapting to dynamic environmental changes. By applying IWO to the optimization of antenna array configurations, it becomes possible to fine-tune the parameters and positions of individual elements, thereby minimizing sidelobes and enhancing the main lobe's performance.

This research not only contributes to the advancement of antenna design but also showcases the versatility of bio-inspired algorithms in solving intricate engineering problems. The exploration of IWO in this context opens avenues for novel approaches in other optimization-intensive domains, highlighting the adaptability of nature-inspired algorithms across diverse scientific disciplines.

The remainder of this paper is structured to provide a comprehensive understanding of the reduction of sidelobe level in antenna arrays, the underlying principles of Invasive Weed Optimization, and the integration of these concepts for improved antenna performance. Through a thorough literature review, we will explore the existing methodologies, challenges, and gaps in current research. Subsequently, the paper will delve into the methodology, presenting the step-by-step application of the Invasive Weed Optimization algorithm to the sidelobe reduction problem in antenna arrays.

Finally, conclusions and future directions will summarize the findings, emphasizing the potential for further research and application in real-world scenarios.

In essence, this paper endeavors to unravel the intricacies of leveraging Invasive Weed Optimization for the reduction of sidelobe level in antenna arrays, offering a nuanced perspective on the synergy between nature-inspired algorithms and cutting-edge antenna design.

II. Literature Review

Reference [3] applied enhanced firefly algorithm (EFA) in reducing or minimizing sidelobe level in antenna array, the result obtained using EFA technique was compared with the result obtained using genetic algorithm (GA), another technique that many researchers have successfully utilized for reduction of sidelobe level. It was mentioned that the performance of EFA was very desirable in minimizing sidelobe level.

In [4], two antennas of annular ring array for an isotropic radiator were modeled to create isoflux radiation patterns for satellites in medium-earth orbit or geostationary orbit. Differential evolution was employed to minimize sidelobe levels and shape the beam.

[5] Explored mitigating the poor convergence speed of the firefly algorithm, minimizing sidelobe levels without significantly affecting the beam width. The results were compared with genetic algorithm outcomes.

[6] Utilized an evolutionary algorithm to have rectangular array antenna patterns synthesized, achieving maximum excitation of antenna elements with a peak sidelobe level below 19dB. [7] Presented a method using differential algorithm to minimize multiple objective function in optimizing conflicting parameters in time-modulated linear antenna arrays for low sidelobe patterns.

[8] Combined artificial bee colony and firefly algorithm for pattern synthesis in a satellite's rectangular planar array. Parameters like phase, array element state, and amplitude were modified, and the

performance of the algorithms was compared. FA (firefly algorithm) and ABC (artificial bee colony) algorithm demonstrated superiority.

[9] Delved into circular antenna array design, focusing on concentric circular arrays made up of isotropic radiators to optimally reduce sidelobe levels. The firefly algorithm outperformed other optimization techniques like particle swarm optimization and genetic algorithms.

Authors in [10] employed the firefly algorithm to optimize both planar and linear array antennas, showcasing its effectiveness through three case applications. These applications demonstrated the algorithm's efficacy in achieving desired optimizations, particularly for planar array antennas. The studies included scenarios such as optimizing isotropic antennas in a non-uniformly spaced linear array, synthesizing radiators on a nanosatellite forming an irregularly spaced linear array, designing a non-uniformly spaced planar array with radiators on a nanosatellite, and optimising a three-part planar-antenna-array for controlling the beam with parallel sidelobe level control.

In [11], the synthesis of linear antenna arrays was addressed using the firefly algorithm with emphasis on controlling element excitation amplitudes. A comparison of the FA with PSO, SADE (Self-Adaptive Differential Evolution), and Tajuche method of Optimization favored the FA. In [12], a method known as biogeography-based optimization to reduce high sidelobe level while achieving deep nulls. In fact, methods such as flower pollination algorithm, firefly algorithm, CS-based algorithm, hybrid algorithm that combines different types of algorithms, and other methods have been used at different times to minimize sidelobe level in antenna array [3, 13-20]

III. Materials and Method

3.1 Materials

Key materials that were used in this work include personal computer and a software, matlab programming software that was used for simulation. The software was already installed in the personal computer prior to the work.

3.2 Method

The method adopted has to do with system model formulation, step-by-step implementation of IWO algorithm, and simulation.

3.3 Invasive Weed Optimization (IWO)

Invasive weed optimization (IWO) is a well-known innovative optimization technique that is inspired by weed colonization. In this very approach, the population consists of weeds, each characterized by a collection of decision variables. Weeds, known for their vigor and invasiveness, pose real danger and threat to wanted plants in the farm.

The application of invasive nature of weeds in optimization algorithm follows the following procedure:

Population initialization: this is where the initial population of the weeds in a particular region or space is specified. In the area of invasive weed optimization, the population is the first set of seeds that are dispersed over the entire field or space.

Reproduction based on fitness: In the normal agricultural setting, not all weeds the same strength. Some plants can adapt very easily and quickly, producing offspring in large numbers. Others, on the other hand, fade quickly and die. Therefore, plants vary in their fitness: those with high fitness are known to produce large offspring while those with low fitness do not. Hence, in invasive weed optimization, the calculation of the fitness of the initial population is done, and each plant is given the opportunity of producing seeds based on its peculiar fitness.

Seeds spatial dispersion or distribution: This is where all the seeds that are randomly generated based on the value of the fitness are scattered within the original weed. When it comes to invasive weed optimization algorithm, after the seeds are generated, they are randomly dispersed across the region. Thereafter, there is a normal distribution with zero mean. The standard deviation will have a minimum and maximum value because there is a reduction in standard deviation when approaching optimal solution.

Competitive elimination: In usual agricultural situation, dispersing seeds over a given region and through reproduction, an entire area is covered. Farmers try to minimize the growth of the seeds and weeds. If the number of seeds is small and a plant does not have offspring, eventually such plant will no longer exist. In invasive weed optimization, the entire population of seeds and weeds are combined, but the population that is not fit owing to the maximum allowable population is eliminated.

3.2.1 Model of the System

Antenna array can have varying degree of elements. Assuming that isotropic radiators (radiators that are radiating equally in all directions) are employed or used. Based on the superposition principle of electromagnetic wave, an array factor can be expressed as [19]

$$AF(\emptyset) = \sum_{m=-N}^{N} I_m \, Cos(kx_m Cos\emptyset + \alpha_m) \quad (1)$$

Where k is the wave number, I_m is the excitation current belonging to the m^{th}element, $x_m$is the m^{th} element's location, $\emptyset$ represents the azimuth angle, α_m is the phase of the m^{th} element. It should be noted that the array factor equation (1) is for linear antenna array. For circular antenna array, the array factor is given by:

$$AF(\theta, \emptyset) = \sum_{i=1}^{N} I_m \exp(j\,[kaSin\vartheta Cos(\emptyset - \emptyset_m) + \alpha_m) \quad (2)$$

Where, $ka = \frac{2\pi}{\lambda} a$ (3)

The target of this work is to minimum sidelobe level. One of the key things that affect the beam pattern is the excitation current. For this reason, an optimum set of excitation currents for all the elements must be determined to realize a much lower sidelobe level. this requires formulating an optimization problem that has to be minimized subject to certain constraints.

3.2.2 Implementation Procedure for Invasive Weed Optimization

The procedure for implementing the IWO algorithm is carefully illustrated in Figure 1.

First, the population of weeds and their locations are randomly generated and initialized. The fitness of each seed is then calculated as the next step. Immediately after the calculation of each seed's fitness, seeds are reproduced based on their fitness value, and the newly reproduced seeds are around the search space. Like the original seeds, the fitness of the newly reproduced seeds are also calculated and some are eliminated based on their fitness value in the colony. After the elimination of some seeds the termination criteria is reached, the process is stopped, if not, the process is repeated with the calculation of the fitness each of the original seeds.

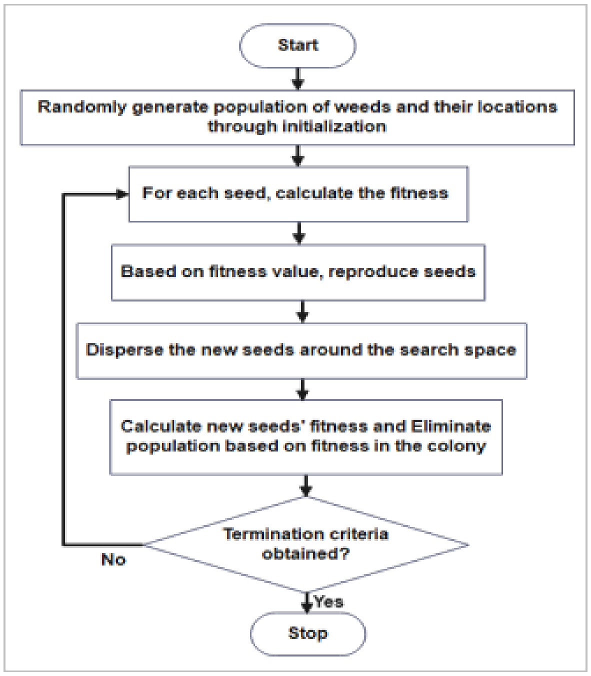

Figure1: Flowchart of the Invasive Weed Optimization Algorithm.

3.2.3 Simulation

Matlab was used in the simulation of the beam pattern synthesis, aiming to bring down the level of sidelobe in antenna array. Parameter fine-tuning is one of the first things to be done. In this, the parameters of the invasive weed optimization algorithm are adjusted or fine-tuned for optimal beam pattern synthesis. Thereafter, use of invasive weed optimization was simulated and compared with other optimization techniques like particle swamp optimization and biogeography-based optimization. The initial and final standard deviation values (σ_{in} and σ_{fi}), which are very critical in updating the invasive weed optimization algorithm, are tuned jointly. 1600 points were used for the tuning test, and the tuning was repeated for 40 different times independently. The initial and final standard deviation values used in the tuning are the same: 0.01, 0.1 and 0.01, 0.1, respectively, and the steps are both 0.002.

IV. Results and Discussion

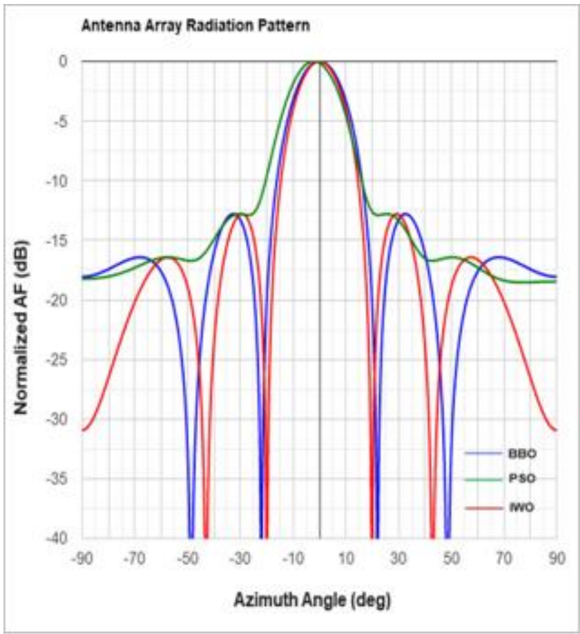

Figure 2: Radiation Pattern for Antenna Array

Figure 2 illustrates the synthesis of antenna beam pattern obtained using invasive weed optimization algorithm, biogeography-based optimization, and particle swamp optimization. Of the three algorithms, the invasive weed optimization is seen to have the lowest sidelobe level.

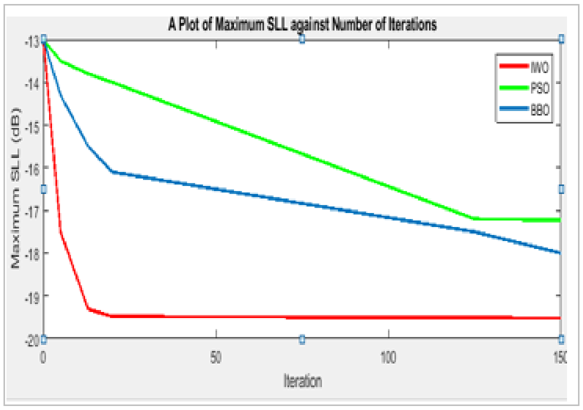

Figure 3: A Plot of Maximum Sidelobe Level against Number of Iterations

The plot of maximum sidelobe level of the antenna array against the number of iterations reveals that for the three optimization techniques used in the work, invasive weed optimization algorithm outperformed the other two methods (Particle Swamp Optimization and Biogeography-Based Optimization). This was followed by Biogeography-Based Optimization. This shows that using Invasive Weed Optimization Algorithm, sidelobe level can be minimized considerably, thereby improving the performance of the antenna in terms of transmission and reception of signals.

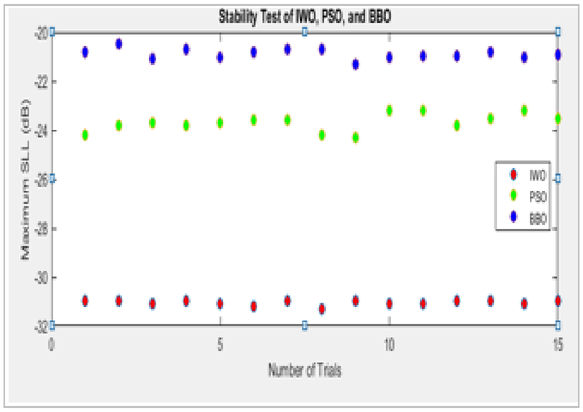

Figure 4: A Scatter Plot of the Stability Test of three Different Algorithms (IWO, BBO, & PSO)

Figure 4 shows a comparative plot of the maximum sidelobe level of IWO, BBO, and PSO algorithms against number of trials. As can be seen from the plot, IWO maintains lowest number of sidelobe, indicating its effectiveness in improving the performance of antenna array through sidelobe level reduction.

V. Conclusion

In this paper, invasive weed optimization was used to minimize the level of sidelobe in antenna array. The effectiveness of the invasive weed optimization algorithm in minimizing the level of sidelobe in antenna array was clearly seen in the comparative examination of the algorithm with two other algorithms such as the biogeography-based optimization algorithm and the particle swamp optimization, where it was shown that of all the three algorithms, invasive weed optimization algorithm had the lowest sidelobe. It was also clear that the invasive weed optimization algorithm, in terms of stability, performed better than the other two. This means that it is more stable than the PSO and BBO algorithms.

References

[1] Sun G., Liu Y.H., Zhang J. Wang A.M. & Zhou X. (2016). Node Selection Optimization for Collaborative Beamforming in Wireless Sensor Networks, *Ad Hoc Networks,* 37, 389-403

[2] Kumar D., Gandhi B.G.R. & Bhattiacharjya R.K. (2020). Introduction to Invasive Weed Optimization. DOI: 10.1007/978-3-030-26458-1_12

[3] Kingsley E.O. (2020). The Issue of Sidelobe Level in Antenna Array: The Challenge and the Possible Solution. Intechopen. doi:10.5772/intechopen.106344

[4] Ibara M., Andrade A.G. Panduro M.A. & Mendez A. (2014). Design of Antenna Arrays for Isoflux Radiation in Satellite Systems. In: Proceedings of 33rd International Performance, computing and Communications Conference. IEEE. Austin, Tx. P.

[5] Bhagya K.N.K.S, & Venkateswara N.R. (2020). Optimization of SLL of Linear Array Antennas Using Enhanced Firefly Algorithm. *International Journal of Engineering Research and Application,* 10: 19-23.

[6] Debasis M., Ved P.R., Anirban C. & Anup K.B. (2018). Synthesis of Dual Radiation Pattern of Rectangular Planar Array Antenna Using Evolutionary Algorithm. ICTACT Journal on Communication Technology. 6: 1146-1149.

[7] Mandal S.K., Mahanti G.K., & Ghatak R. (2013). Differential Evolution Algorithm for Optimizing the Conflicting Parameters in Time-Modulated Linear Array Antennas. *Progress in Electromagnetic Research B, 51:* 101-118.

[8] Chatterjee A., Mahanti G.K. & Ghatak G. (2013). Synthesis of Satellite Footprint Patterns from Rectangular Planar Array Antenna by Using Swamp-Based Optimization Algorithms. *International Journal of Satellite Communication and Networking.* John Wiley Sons. DOI:10.1002/sat.1055.

[9] Ashraf S. & Nihad D. (2013). Circular Antenna Array Synthesis Using Firefly Algorithm. Department of Electrical Engineering, Jordan University of Science and Technology. Wiley, UK. DOI:10.1002/mmce.20721

[10] Eduardo Y. & Marcos V.T.H. (2019). Optimization of Planar Antenna Arrays Using Firefly Algorithm. *Journal of Microwaves, Optoelectronics and Electromagnetic Application.* 18:35-37. DOI: http://dx.doi.org/oi.1590/2179-107420gr18:11646.

[11] Kamaldeep K. & Vijay K.B. (2013). Optimization of Linear Antenna Array Using Firefly Algorithm. *International Journal of Engineering Research and Technology (IJERT).* 2:2307-2313.

[12] Sun G., Liu Y. Li H., Liang S., Wang A. & Zhang Y. (2017). Beam Pattern Design of Circular Antenna Array via Efficient Biogeography-Based Optimization AEU-International Journal of Electronics and Communications, 79, 275-285.

[13] Sun G., Liu Y., Li J., Zhang Y. & Wang A. (2017). Sidelobe Reduction of Large-Scale Antenna Array for 5G Beamforming via Hierarchical Cuckoo Search, *Electronics Letters*, 53(16), 1158-1160.

[14] Saxena P. & Kothari A. (2016). Ant Lion Optimization Algorithm to Control Sidelobe Level and Null Depths in Linear Antenna Arrays, *AEU-International Journal of Electronics and Communications, 70(9)*, 1339-1349.

[15] Sharaga A. & Dip N. (2014). Circular Antenna Array Synthesis Using Firefly Algorithm, *International Journal of RF and Microwave Computer-Aided Engineering*, 24(2), 139-146.

[16] Singh U. & Salgotra R. (2018). Synthesis of Linear Antenna Array Using Flower Pollination Algorithm, *Neural Computing and Applications*, 29(2), 435-445.

[17] Todnatee S. & Phongcharoenpanich C. (2016). Iterative GA Optimization Scheme for Synthesis of Radiation Pattern of Linear Array Antenna, *International Journal of Antennas and Application*, ArticleID:7087298.

[18] Jayaprakasam S., Rahim S. & Leow C.Y. (2015). PSOGSA-Explore: A New Hybrid Metaheuristic Approach for Beam Pattern Optimization in Collaborative Beamforming, *Applied Soft Computing*, 30, 229-237.

[19] Singh U. & Salgotra R. & Rattan M. (2016). A Novel Binary Spider Monkey Optimization Algorithm for Thinning of Concentric Circular Antenna Array, *IETE Journal of Research*, 62(6), 736-744.

[20] Sun G., Liu Y., Chen Z., Zhang Y., Wang A. & Liang S. (2017). Thinning of Concentric Circular Antenna Arrays Using Improved Discrete Cuckoo Search Algorithm, *in 2017 IEEE Wireless Communications and Networking Conference (WCNC)*, 1-6, San Francisco, CA, US