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A parallel implementation of seeker optimization algorithm for designing circular and concentric circular antenna arrays

Kerim Guney[a], Suad Basbug[b,*]

[a] Faculty of Engineering, Department of Electrical and Electronics Engineering, Nuh Naci Yazgan University, Kayseri, Turkey
[b] Department of Computer Programming, Vocational College, Nevsehir University, 50300 Nevsehir, Turkey

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ABSTRACT

In this paper, a parallel version of seeker optimization algorithm (SOA) is proposed for designing circular and concentric circular antenna arrays with the low sidelobe levels at a fixed beamwidth. The SOA is a relatively new evolutionary optimization algorithm based on the concept of simulating the act of humans' intelligent search with their memory, experience, and uncertainty reasoning. In this work, The SOA has been parallelized by benefiting from its dividable population form. The numerical results show that the design of circular and concentric circular antenna arrays using the parallel SOA provides good sidelobe levels with a fixed beamwidth. The quality of results obtained by the parallel SOA is checked by comparing with those of several evolutionary algorithms in the literature.

1. Introduction

Antenna arrays are widely used in modern communication and radar systems. Linear antenna arrays cannot provide flexible solutions in terms of steering capabilities. This limitation can be eliminated by using planar arrays which have the beam steering ability in two planes. Circular and concentric circular arrays are common choice when beam scanning is required in azimuth through 360° without mechanical rotation. These arrays are used in many fields including satellite communication, radar, sonar, and navigation systems [1,2].

Antennas with the low sidelobe levels at a fixed main beamwidth are required in many communication systems. One of the major advantages of antenna arrays is that synthesis of low-sidelobe and narrow-beam patterns can be achieved by controlling their element excitations and positions. The classical optimization techniques used for antenna arrays synthesis are likely to be stuck in local minima if the initial guesses are not reasonably close to the final solutions. In order to overcome the disadvantages of classical optimization techniques, several evolutionary methods [3–15], varying in accuracy and computational effort, have been proposed and used to synthesize antenna arrays.

In this paper, we propose a parallel seeker optimization algorithm (SOA) for designing non-uniform circular and equally spaced concentric circular antenna arrays with the low sidelobe levels at fixed beamwidths. The SOA originally proposed in Ref. [16] is a relatively new evolutionary computation technique based on the concept of simulating the act of human intelligent searching. In Refs. [16–25], SOA was compared with biogeography-based optimization (BBO) and different and hybrid versions of particle swarm optimization (PSO), genetic algorithm (GA), differential evolution (DE), ant colony optimization (ACO), simulated annealing (SA), tabu search (TS) and bacterial foraging (BF) for the benchmark functions and particular engineering problems. In Refs. [17,18], the SOA has been applied to optimal reactive power dispatch on standard IEEE 57- and 118-bus power systems, and compared with several optimization algorithms including GA, PSO, and DE. It is clear from the results obtained in Refs. [17,18] that the proposed approach is superior to the other listed algorithms and can be efficiently used for optimal reactive power dispatch. An SOA-based digital filter design method has been presented in Ref. [19], and the benefits of SOA for designing digital IIR filters have been studied. It was illustrated in Ref. [19] that SOA has better, or at least equivalent, global search ability and convergence speed than GA, four version of PSOs, and three version of DEs for most of the chosen and widely used problems. In Ref. [20], the performance of SOA was studied with a challenging set of benchmark problems for function optimization. The comparisons of SOA, DE, and

* Corresponding author. Tel.: +90 384 2281140; fax: +90 384 2152671.
E-mail address: suadbasbug@gmail.com (S. Basbug).

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three modified PSOs show that SOA has better global search ability and faster convergence speed for the most chosen benchmark problems [20]. A hybrid method combining SOA and sequential quadratic programming (SQP) for solving dynamic economic dispatch (DED) problem with valve-point effects including generator ramp-rate limits has been proposed in Ref. [21]. It was shown that the proposed hybrid SOA-SQP method is giving higher quality solutions than the reported methods for DED problem with valve-point effects [21]. The application of the SOA to tuning the structures and parameters of artificial neural networks (ANNs) was presented in Ref. [22] as a new evolutionary method of ANN training. The results in Ref. [22] showed that SOA can simultaneously tune the structures, the weight values and the parameter of regularization performance function. Moreover, it was shown that SOA is better than, or at least comparable to, DE and two PSO algorithms. It was also illustrated that the ANNs with link switches trained by SOA not only have much less number of links but also have better or equivalent learning capabilities than ones by back propagation algorithms [22]. SOA was applied to optimal modeling of the proton exchange membrane fuel cell (PEMFC) by using a fuel cell test system in Ref. [23]. The simulation results showed that SOA has better performance than other famous versions of PSO and DE algorithms [23]. SOA was used in Ref. [24] for the solution of the constrained economic load dispatch problems in different power systems considering various non-linear characteristics of generators. The results of SOA were compared with those of BBO, different and hybrid versions of PSO, DE, GA, ACO, BF with Nelder–Mead algorithm, improved fast evolutionary programming, and Hopfield model. The comparison results showed that the SOA has the ability to converge to a better quality near-optimal solution and possesses better convergence characteristics and robustness than the other algorithms [24]. In our previous work [25], we used basic SOA for null steering of linear antenna arrays by controlling the position-only, phase-only, and amplitude-only. Several numerical examples of Chebyshev pattern with the single, multiple, and broad nulls imposed at the directions of interference were given to illustrate the performance and flexibility of the proposed algorithm. For a comparison, the nulling patterns obtained by SA and TS algorithms were also given. From the null depth level and the maximum side lobe level points of view, the performances of the patterns obtained by SOA are mostly better than those of SA and TS. Furthermore, the results of SOA were statistically compared with those of SA and TS algorithms. The statistical results of simulations showed that SOA is superior to the other compared algorithms [25]. In this paper, the *parallel* SOA is used for designing circular and concentric circular antenna arrays with the low sidelobe levels at a fixed beamwidth.

Parallel computing is a form of computation in which many calculations are carried out simultaneously [26]. Computation problems, which can be divided into smaller parts are able to be efficiently solved in the parallel computing systems. Since evolutionary algorithms, like other bioinspired algorithms, need high computation power, they have come closer to parallel computing systems during the last years [27]. Several evolutionary algorithms were parallelized with the help of their intrinsically parallel and distributed nature [28]. Parallelized evolutionary algorithms did not escape the attention of antenna design researchers as well as other scientists. In Ref. [29], a parallel GA was used for design dual-band patch antenna intended for wireless communication applications. The optimal patch geometry that exhibits good agreement with calculations was found with the help of the robustness of GA and the speed of cluster supercomputing [29]. A parallel PSO/finite-difference time-domain (FDTD) was proposed in Ref. [30] for designing multi-band and wide-band patch antennas. It was showed that the parallel PSO/FDTD optimizer is able to achieve the optimum design for specified antenna performance in an effective manner. In Ref. [31], the structural parameters of the three-dimensional fishbone antenna were optimized in an automated design, making use of the GA in conjunction with numerical electromagnetic codes and cluster parallel computation. The optimization process was targeted to achieve a high endfire gain and good impedance match. By considering the simulation results, a prototype was fabricated and tested. The measured radiation pattern and the return loss of the antenna were compared with the computational results, and a good agreement was observed [31]. A parallel GA optimization tool was developed for the synthesis of arbitrarily shaped beam coverage using planar 2D phased-array antennas in Ref. [32]. A benchmark 10×10 (100) element array was employed, and various results of optimized coverage patterns were shown herein to illustrate the effectiveness and validity of the technique using complex, amplitude-only, and phase-only optimization of the array weights [32].

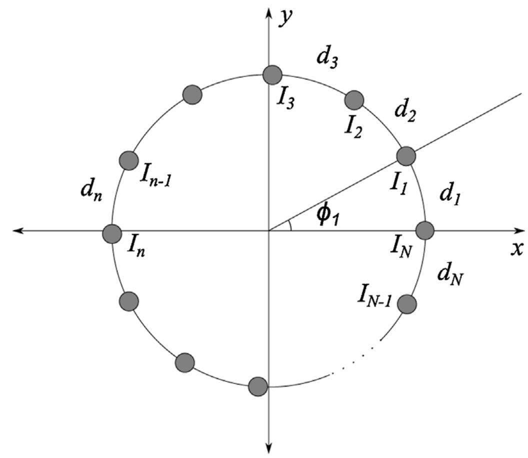

Fig. 1. Geometry of a non-uniform circular antenna array with N isotropic radiators.

The SOA used in this work has been parallelized by using MPICH2 [33] which is a highly portable implementation of the message passing interface (MPI) standard. The MPI is a library of message-passing routines and it has a dominant position in the parallel computing [28]. The parallel SOA proposed in this paper has a kind of master–slave model. The master is a single computer and manages all communication among the slave computers. The iterative optimization process based on SOA structure is performed in the computers acting in the role of slaves. The master computer collects the best values from the slaves and distributes the best of them to the slaves in the same connection. The parallel SOA uses the non-blocking communication technique of MPI in order to allow the slaves to allocate more time to their optimization task.

The remaining sections of this paper are organized as follows: Section 2 briefly explains the formulation of the problem. Section 3 describes the details of parallel SOA algorithm. The numerical results are presented in Section 4 and the conclusion is made in Section 5.

2. Problem formulation

2.1. Non-uniform circular antenna array

Let us assume that a circular antenna array of N antenna elements non-uniformly spaced on a circle of radius r in the x–y plane, as shown in Fig. 1. If the elements in the circular antenna array