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Adaptive Uniform Circular Array Synthesis Using Cuckoo Search Algorithm

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Abstract

Naturally suited array geometry for 360˚ coverage is the uniform circular array (UCA). A comparison of two types of uniform circular array configurations is presented in this paper. Due to its symmetrical geometry UCA is always targeted which results in minimal change inside lobe levels and beam width when scanned by a phased array antenna. Particle Swarm Optimization and Cuckoo algorithm are used for the calculation of complex weights of the array elements. Comparisons are drawn in the context of adaptive beam forming capabilities. Obtained results suggest that planar uniform circular array (9:10) using Cuckoo algorithm, has better beam forming properties with also reduced side lobe levels when compared to other geometry.

Keywords

Smart Antennas, Antenna Arrays, Uniform Circular Array, Planar Uniform Circular Array, Particle Swarm Optimization, Cuckoo Search

1. Introduction

The applications of antenna arrays have been very useful for the past few decades to synthesize far field radiation pattern. In general, linear or planar antenna arrays are used for this purpose. The goal is achieved by controlling basic parameters namely number of elements: inter element spacing, relative current amplitude and phase of the elements. A circular array may be also specified by using the same parameters [1]. Most often a circular is specified using N elements of equally spaced isotropic sources [2]. The array factor is calculated according to the excitations produced by a given function. A circular array with a center element can be designed [3] and a planar arrangement of this array increases the steering capability of the array, with sidelobe levels being considerably reduced [4]. The

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purpose of this work is to get an in-depth knowledge on uniform circular arrays and to find out ways which help the above mentioned arrays to perform better in whatever application they are used.

Due to their adaptive features, smart antennas gained much attention in the communication industry. Adaptive nulling uses an estimate of signal correlation matrix to find out adapted weights. These algorithms are primarily based on Wiener Hopf solution and they find the adaptive weights by optimizing certain parameters taken like signal to noise ratio [5]. Spatial Filtering is achieved with the use of adaptive antenna array, the signal received on each antenna are first weighted and then summed to obtain the output of spatial filter [6]. Smart antennas employs to main techniques; switched beam array where the beam direction is selected from a set of predetermined beams, and phased array in which the main beam is steered along a specified direction [7] [8]. A change in the excitation of both amplitude and phase is necessary to steer the beam towards desired direction. Algorithms such LMS, CMI, SMA, RLS are used for this purpose.

Genetic algorithms (GA) are a class of search algorithms typically based on mechanics of natural selection and natural genetics. Survival of the fittest is combined among the string structures with a structured yet arbitrary information exchange to form a unique search algorithm with some of the experimental flair of human search [9]. They started to show some appeal in optimization of radiation patterns and were also applied in the problem solving of thinning linear and planar arrays, so that sidelobe levels are reduced over a specified range of bandwidth and scan angle [10]. PSO on the other hand is also a class of evolutionary algorithm used for the purpose of multidimensional optimizations in many fields. This algorithm is mainly based on the independent particles social interaction for finding the optimal solution.

Developed by XinsheYang and Suash Deb in 2009, CSA is a nature inspired meta heuristic search algorithm. The algorithm is typically based on the behaviour of cuckoo bird. Inspired from the reproduction strategy of cuckoos, the algorithm comes under the category of evolutionary techniques for the purpose of global optimization [11]. In this paper, the radiation pattern and performances for two types of circular arrays are studied using Cuckoo Search Algorithm (CSA) and Particle Swarm Optimization (PSO).

Out of the four sections divided in this paper. Section 2 deals with the geometry of given circular arrays. Section 3 deals with evolutionary techniques implemented. Section 4 deals with the analysis of results obtained by simulation and Section 5 finally concludes the paper.

2. Uniform Circular Arrays

Array Configuration

Two types of arrays configurations are considered namely, Uniform Circular array (UCA (19)), Planar Circular array (PUCA (9:10). The Uniform Circular array geometry is in **Figure 1** [8].

The array factor described for the far field radiation pattern is given by (1) [2] [8]

$$AF(\theta,\phi) = \sum_{n=1}^{N} a_n \mathrm{e}^{jkr\sin\theta\cos(\phi_0-\phi_n)} \tag{1}$$

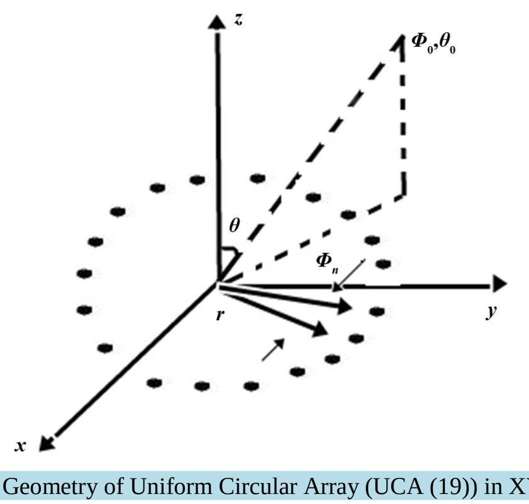

Figure 1. Geometry of Uniform Circular Array (UCA (19)) in XY-plane.

where $k = 2\pi/\lambda$, a_n is the excitation and ϕ_n is the azimuthal angle of the n^{th} element. N represents the number of elements. The radius r is set at 1.97λ and the element separation is 0.64λ.

The PUCA configurations are given in the **Figure 2** [3] [4].

The array factor for the above geometry is given by (2) [8].

$$AF(\theta,\phi)=\sum_{m=1}^{M}\sum_{n=1}^{N}a_{mn}\mathrm{e}^{jkr_m\sin\theta\cos(\phi_0-\phi_{mn})} \tag{2}$$

where a_{mn} and $\emptyset_{mn}$ are the excitation and the azimuth angle of n^{th} element in m^{th} ring. The radius of outer ring r_1, set to 1.96λ and radius of inner ring r_2 is set to 1.23. N is the total number of N_{th} elements in M_{th} rings.

3. Evolutionary Techniques

Adaptively steering the main beam and simultaneously nullifying the interfering signals is one of the important features offered by phased array antennas. The technique is called as adaptive beam forming.

3.1. Particle Swarm Optimization

In PSO, an optimal solution is searched by the algorithm from a population of available solutions termed as particles. (p_{best}) is the best solution achieved by any particle (g_{best}) the global best solution, are compared and stored for future iterations. The velocity towards p_{best} and g_{best} are updated in a iterative manner [12] [13].

With PSO, an optimal solution from a population of solutions is searched by the algorithm, which are normally (3) (4) [5]

$$v_{n+1}=w*v_n+c_1r_1\left(p_{best,n}-x_n\right)+c_2r_2\left(g_{best,n}-x_n\right) \tag{3}$$

$$x_{n+1}=x_n+v_{n+1} \tag{4}$$

where v_n is the particle velocity and x_n is the particle position, c_1 and c_2 are taken to be scaling constants.

The fitness function and correlation matrix for the received signal is given by (5) (6) [12]

$$f(w)=\frac{\left|w^H\cdot x_s\right|^2}{w^H\cdot R_{xx}\cdot w} \tag{5}$$

$$R_{xx}=R_{ss}+R_{ii}+R_{nn} \tag{6}$$

R_{ss} is the correlation matrix of desired signal, R_{ii} is the correlation matrix of interference signal and R_{nn} is the correlation matrix of the noise signal

3.2. Cuckoo Search Algorithm (Figure 3)

Through simulation conducted on different standard test functions, CS proved to be more efficient in finding the

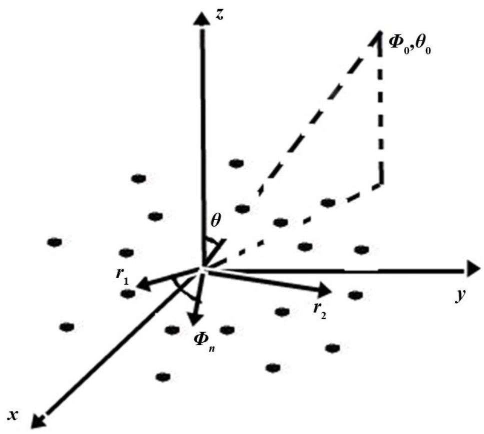

Figure 2. Geometry of Planar Uniform Circular Array (PUCA (9:10)) in XY-plane.

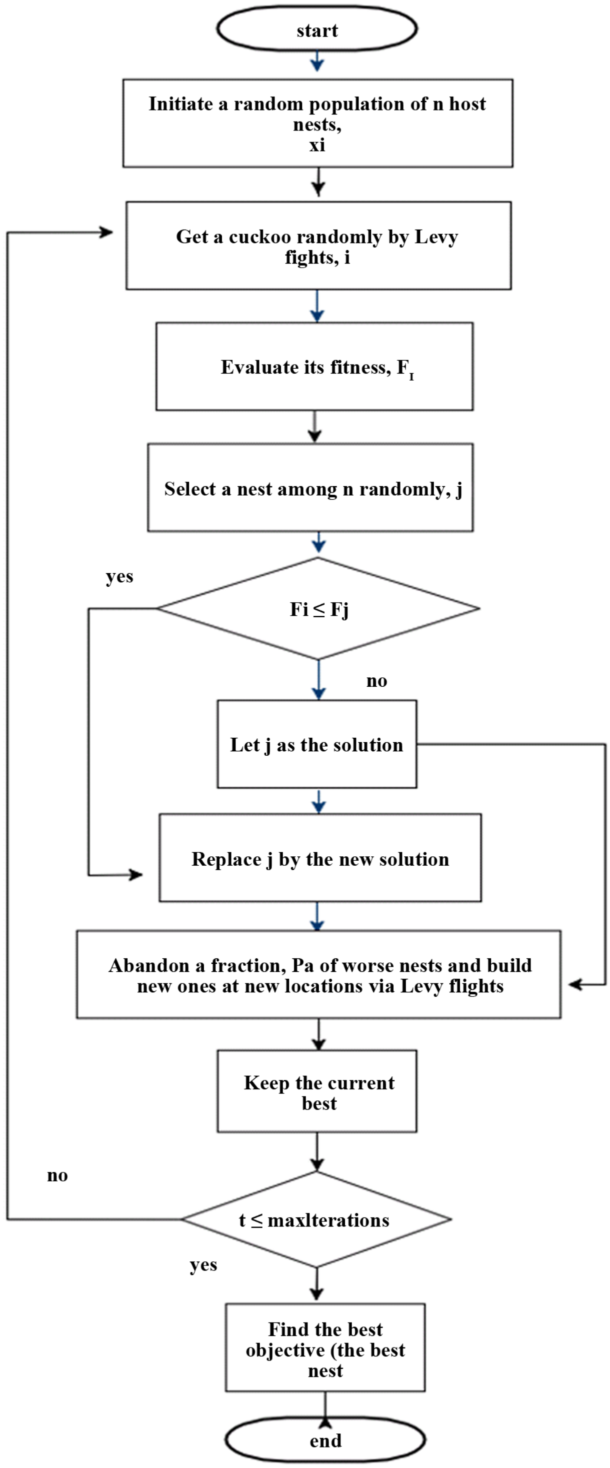

Figure 3. Flowchart of cuckoo search algorithm.

global optima with high success rate [14]. The search algorithm is developed based on the fact that, as soon as a host bird on coming to the knowledge of eggs not being their own, it simply discards those alien eggs or simply abandons the entire nest to build a new one elsewhere. For simplicity, the algorithm is described in the following assumptions made [15].

1) Each cuckoo lays one egg at a time, which represents a set of solutions, dumps it in randomly chosen nest.

2) The best nests containing high quality of eggs (solutions) will be carried over to the next generations.

3) The number of host nests available being fixed, and an alien egg being discovered by a host with probability $P_a \in [0,1]$. In this case, the host bird can either throwaway the egg or discard the nest to build a new one in a completely new location.

P_a of n nests, in the third assumption is replaced with new nests (new random solutions).

When generating new solutions $X_{(t+1)}$ for a cuckoo i, using the below equation a Lévy flight is implemented [15]

$$X_i^{t+1} = X_i^t + \alpha \otimes \text{Levy}(\lambda) \tag{7}$$

where α ($\alpha > 0$) represent step size, $\otimes$ represent entry-wise multiplication.

Lévy flights provide random walk, while Levy distribution for large steps draws random steps.

$$\text{Levy} \sim u = t^{-\lambda}, \; (1 < \lambda \le 3) \tag{8}$$

An interesting point to mention here is, if the cuckoo's egg is almost similar to host's egg then the chance of egg being discovered is less. This results in difference of solutions. Therefore, it is highly useful to do a random walk in a different approach with some random step size. Mantegna algorithm offers the most efficient and a straight forward way for the generation of steps of Lévy flights.

The steplength "*s*", in Mantegna's algorithm, is given by [15]

$$S = \frac{u}{\left|y^{1/\beta}\right|} \tag{9}$$

where $0 < \beta \le 2$, and u is a stochastic variable, drawn from normal distributions given by [15] $u \sim N\left(\sigma_u^2\right)$

$$\sigma_u = \left\{ \frac{\Gamma(1+\beta)\sin\frac{\pi\beta}{2}}{\Gamma\left[\frac{1+\beta}{2}\right]\beta \cdot 2^{(\beta-1)/2}} \right\}^{1/\beta} \tag{10}$$

Here $\Gamma(z)$ is the Gamma function given by

$$\Gamma(x) = \int_0^\infty t^{z-1} \mathrm{e}^{-t} \mathrm{d}t \tag{11}$$

4. Simulation Results and Analysis

CS comes a class of nature inspired meta heuristic algorithms. The term "meta" refers to "change" and the term "heuristic" generally mean "discovery oriented by trial and error". Step size in CSA refers to the distance travelled by a cuckoo bird for fixed number of iterations. In case of large step size or too small step size leads to a deviation from optimum solution required.

The following are the parameters taken into consideration for cuckoo search algorithm,

- Probability of alien eggs, $P = 0.25$.
- Population size, $D = 55$.
- Number of nests, $N = 40$.
- Maximum iterations, Iterations = 1000.
- Best runs, $i = 10$.
- Simulation software, MATLAB r2009a.

For the analysis of the Uniform Circular Array (UCA (19)) and Planar Uniform Circular Array (PUCA (9:10)), a desired direction is given and number of nulls to be placed was also defined. The number of interfering signals tested was up to four in this paper. Also conclusions are drawn by comparing cuckoo search algorithm (CSA) and particle swarm optimization (PSO) with reference to beam width and side lobe levels (SLL). All the conclusions drawn from the figures are tabulated.

A comparison of the radiation patterns of UCA and PUCA using CSA with 2 interference signals; one at −30˚ and the other at 30˚ (**Figure 4**).

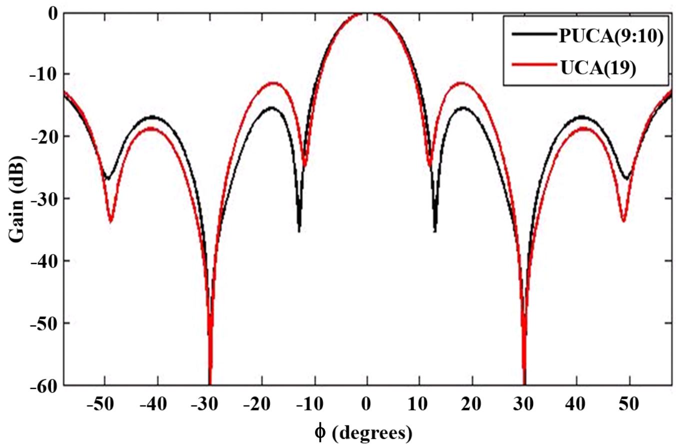

Figure 4. Radiation plot for UCA with 2-interferences using cuckoo search.

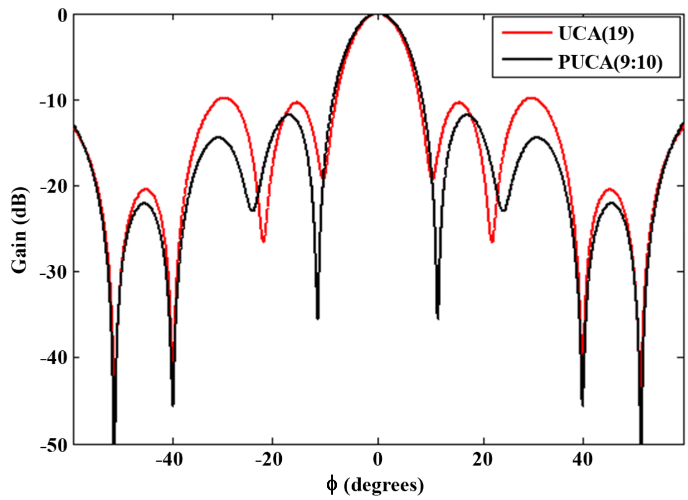

Figure 5. Radiation plot for PUCA with 4-interferences using cuckoo search.

A comparison of the radiation patterns of UCA and PUCA using CSA with 4 interference signals; 40 and −40˚, 50˚ and −50˚ (**Figure 5**).

Plot for radiation pattern showing a comparison between particle swarm optimization and Cuckoo search algorithm for UCA configuration with 2-interference signals; one at 60˚ and the other at −60˚ (**Figure 6**).

Plot for radiation pattern showing a comparison between particle swarm optimization and Cuckoo search algorithm for PUCA configuration with 2-interference signals; one at 45˚ and the other at −45˚ (**Figure 7**).

Simulations conducted show that planar uniform circular arrays have better performance than the other geometry (**Tables 1-3**). A more precise main beam pattern is also seen from the results and half power beam width values. Additionally, it is also proven CSA has better convergence than PSO algorithm which when used with PUCA, provides better results. In this case, SLL for UCA is −3.5 dB and for PUCA it is −11.6 dB. HPBW for UCA is 13.78˚ and for PUCA it is 12.10˚. Therefore, cuckoo search algorithm is better for synthesizing planar uniform circular arrays.

5. Conclusion

It is seen from the results, cuckoo search algorithm has better performance in achieving the global optima, also planar uniform circular array (PUCA(9:10)) using CSA has better beam forming properties with more precise main lobe direction and reduced side lobe levels which were the most required criteria in many industrial, commercial and military applications of antennas. Improved results may be possible when hexagonal arrays and

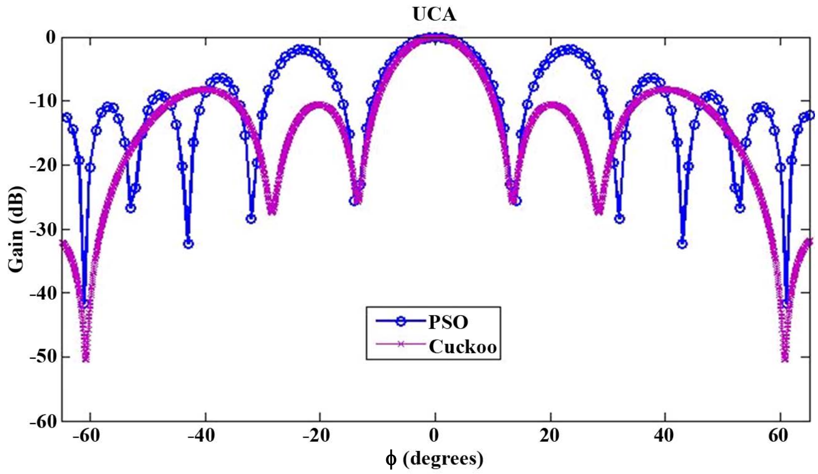

Figure 6. Comparison of PSO and CS for UCA with 2-interferences.

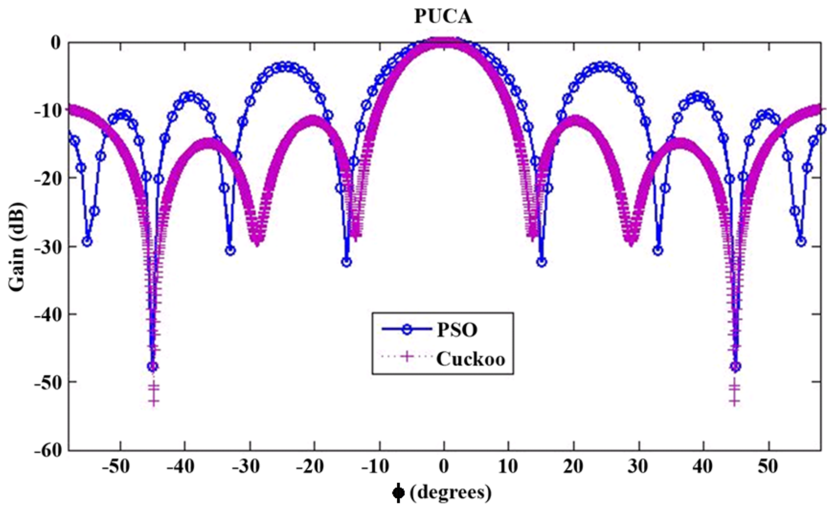

Figure 7. Comparison of PSO and CS for PUCA with 2-interference.

Table 1. Amplitude excitations using Cuckoo Search algorithm.

Algorithm	Number of elements	Array configuration	Amplitudes = [I_1, I_2, …, I_n]
CSA	19	UCA (19)	0.32177, 0.10167, 0.53315, 0.94385, 0.42848, 0.41382, 0.87767, 0.65224, 0.15012, 0.86095, 0.55844, 0.41715, 0.05218, 0.68579, 0.48134, 0.3984, 0.05807, 0.69605, 0.88087
		PUCA (9:10)	0.89609, 0.06028, 0.32556, 0.10063,0.7991, 0.87071, 0.2296, 0.39574, 0.56842, 0.52267, 0.44564, 0.26467, 0.08850, 0.66935, 0.51399, 0.06164, 0.2310, 0.07227, 0.79615

Table 2. Conclusions drawn from **Figure 4** and **Figure 5** using Cuckoo Search algorithm.

Algorithm	Number of interferences	Array configuration	HPBW [Deg.]	SLL (dB)
CSA	2	UCA (19)	11.2˚	−11.49
		PUCA (9:10)	11.24˚	−15.5
	4	UCA (19)	10.36˚	−10.39
		PUCA (9:10)	10.62˚	−12.01

Table 3. Conclusions drawn from comparison betweenPSO and CSA.

Algorithm	Array configuration	HPBW [Deg.]	SLL (dB)
PSO	UCA (19) PUCA (9:10)	14.57˚ 12.42˚	−2.03 −10.59
CSA	UCA (19) PUCA (9:10)	13.78˚ 12.10˚	−3.5 −11.6

octagonal arrays are taken into consideration which may be opted for future scope.

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