Design of Circular Antenna Array using Particle Swarm Optimization

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Abstract

A new technique is proposed for the design of circular antenna arrays using particle swarm optimization. The design problem has been formulated to achieve a desired beamwidth and sidelobe level. This is accomplished by jointly optimizing the excitation amplitude and phase. The results obtained show improvement over conventional linear programming method.

1. Introduction

The antenna arrays are being widely used in mobile and satellite communications. Optimization is the process of finding the optimum values of lengths, spacings, amplitudes or phases of antenna elements in order to obtain a desired radiation pattern. The circular array, in which the elements are placed in a circular ring, is an array configuration of very practical interest. Its applications span radio direction finding, air and space navigation, underground propagation, radar, sonar and many other systems. Recently circular arrays have been surveyed for application in smart antenna applications [1]. The advantage of circular antenna array over linear antenna array is that it does not have any edge elements. Thus directional patterns synthesized by this geometry can be electronically scanned in the azimuthal plane without a significant change in beam shape. Despite this significant advantage, not as much attention has been paid so far for circular antenna array designing [2].

The conventional methods of linear antenna array optimization use a set of linear or non linear design equations and solving them to get the optimal solution. Due to the complexity of the design problem, these methods are not suitable for circular array optimization. The solution lies in the use of evolutionary approaches like Genetic Algorithm(GA) and Particle Swarm Optimization (PSO) of optimization for electromagnetic design [3]. The Genetic Algorithms [4] and Particle Swarm Optimization [5-8] are being widely used for optimization problems in antenna and electromagnetic design problems. In this paper, the circular array has been optimized for side lobe level and beamwidth using PSO.

2. Particle Swarm Optimization

In PSO algorithm, a population of particles (decision variables) is used to find the optimal solution. Each particle represents a candidate solution to the problem. This evolutionary algorithm has been developed through simulation of bird flocking in 2-D space. Attractive features of PSO technique are ease of implementation and non requirement of gradient information.

Initial population of size *m* is selected in feasible space. Each individual *i* has a current position $X_i(k)$, a current velocity $V_i(k)$, $G_{best}(k)$ and P_{besti} be the best position of the group and individual *i* respectively. r_1 and r_2 are two random numbers independently generated. Velocity and position of individual is updated using following relation

$$V_i(k+1) = wV_i(k) + c_1 r_1 [P_{best\,i}(k) - X_i(k)] + c_2 r_2 [G_{best\,i}(k) - X_i(k)] \quad \ldots(1)$$

$$X_i(k+1) = X_i(k) + V_i(k+1) \quad \ldots(2)$$

Steps involved in PSO technique are as follows

Step 1: Select initial particles in feasible space $X_i(0)$, *i* =1, 2, 3…..m.

Also select low initial velocity for each individual in a group. These initial velocities and positions of each individual in a group can be generated by generating random digits in feasible space.
Step 2: Set iteration count k =1 and select relevant constants c_1, c_2 and w.
Step 3: Update velocity and position of each particle using equations (1) and (2).In the process of velocity updating the weighting parameter is defined as follows:

$$w = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{k_{\max}}\right)k$$

Where k_{max} is the maximum number of specified iteration and k is the current iteration.
Step 4:

$$If\ v_{id}(k+1) < v_{d\min}\ then\ v_{id}(k+1) = v_{d\min}\ and\ if\ v_{id}(k+1) > v_{d\max}\ then\ v_{id}(k+1) = v_{d\max}$$

Step 5: Updating of P_{best} and G_{best}. The personal best position P_{best} of each particle of current iteration is updated as follows

$$P_{best\ i}(k+1) = X_i(k+1),\ if\ PI(k+1) < PI(k)$$
$$= P_{best\ i}(k),\ if\ PI(k+1) = PI(k)$$

Where PI is the objective function to be minimized and evaluated at the position of individual i. Further, G_{best} at current iteration is set at the best evaluated value of $P_{best\,i}(k+1)$.
Step 6: Modification of velocities and positions of individual continues till maximum number of iterations specified have been performed.
The w_{max} and w_{min} may be specified in ranges 1.0-0.5 and 0.5-0.1 respectively and the values of c_1 and c_2 are selected equal as 1 or 2.

3. The Design Process and Simulation Example

Consider a circular array of M isotropic elements equally spaced around a circle of radius a, as shown in Fig.1. M is assumed to be a even number. Let the excitation amplitude in all elements be I and the phases in the n, $-n$, n', and $-n'$th elements be φ_n, φ_{-n}, $\varphi_{n'}$, and $\varphi_{-n'}$ respectively. The radiation pattern in the plane of the array is given by,

$$E(\phi) = 2\sum_{n=-N}^{n=N} I_n \cos\left[ka\cos\left(\phi + (2n\pi/M)\right) + \varphi_n\right] \qquad \text{….. (3)}$$

Where $K = 2\pi/\lambda$ and the phases are assumed to be

$\varphi_n = \varphi_{-n} = -\varphi_{n'} = -\varphi_{-n'}$ for n = 0, 1, 2, 3, …., N-1

$\varphi_N = \varphi_{-N} = 0$, for $M = 4N$

In (1), $I_n = I$ except that $I_n = I_{-n} = I/2$ for $M = 4N$ and $I_n = I_{-n} = 0$, for $M = 4N$-2.

The following fitness function has been used to evaluate the fitness or cost,

$$F = 4(SLL + SLLD)^2 + (BW - BWD)^2 - 2\,(AF(1))$$

Where SLL and BW are actual sidelobe level and beamwidth of the current design and $SLLD$ and BWD are desired values of sidelobe level and beamwidth. $AF(1)$ is the value of array factor at 0°, so as to fix the maxima at 0°. Consider a 36 element circular array with ka = 9. The desired values of sidelobe level and beamwidth have been kept as 17 dB and 48° respectively. The PSO has been run for 500 iterations and results have been noted. The number of particles taken is 200 and the values of c_1 and c_2 are 1 and 0.95 respectively. The weight vector w is linearly damped from 0.9 to 0.2. The algorithm terminates with success at global optimum point. Table 1 shows the optimum values of amplitudes and phases obtained. Figure 2 shows the normalized patter obtained with comparison to that obtained using conventional Linear Programming Method [9]. Clearly, PSO shows better results in terms of both sidelobe level and beamwidth.

4. Conclusion

In this paper, Particle Swarm Optimization algorithm has been used to obtain the minimum side lobe level and optimum value of beamwidth of 36 element circular antenna array. Results show the efficiency of PSO in solving the

optimization of circular antenna array over Linear programming method. The sidelobe is better by 1.18 dB and beamwidth has been narrowed more by 6 degrees. Both the sidelobe level and beamwidth are better optimized using PSO. The advantages of using PSO are (i) chances of getting global optimum solution are increased and (ii) implementation is easy. Further, other design objectives like null positioning can be easily included in the fitness function and optimized using PSO. PSO can be further studied for optimization of conformal arrays and arrays of practical radiators.

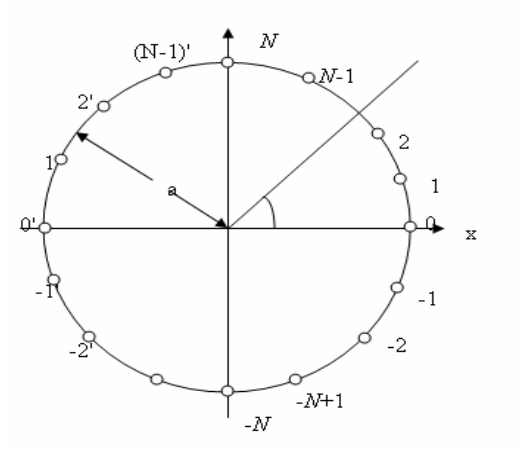

Figure 1: Geometry of a circular antenna array

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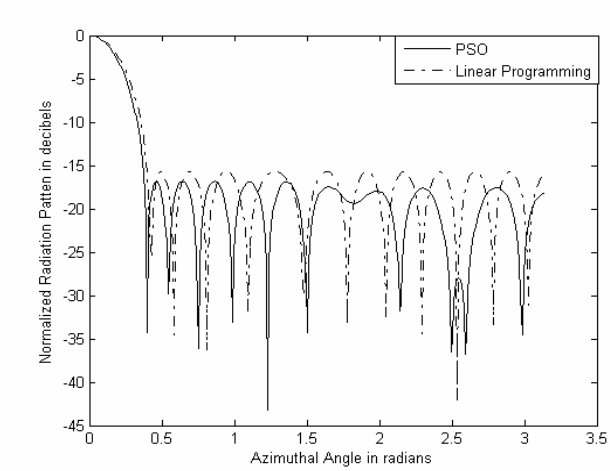

Figure 2: Normalized radiation pattern of 36 element circular antenna array

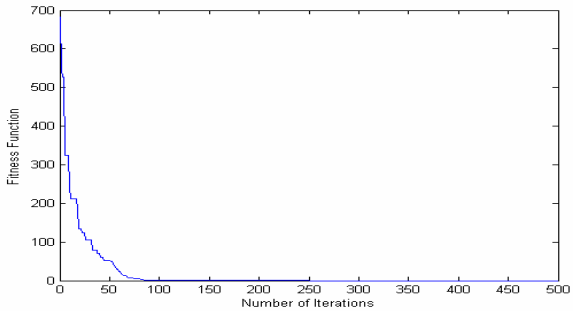

Figure 3: Convergence Characteristics of PSO algorithm for 36 element circular antenna array design problem,
Table 1: Comparative results

M=36	Linear Programming Method		Particle Swarm Optimization	
n	Amplitude	Phase	Amplitude	Phase
0	1.0	35.60	0.30	171.18
1	1.0	314.59	0.96	171.08
2	1.0	45.14	0.62	227.14
3	1.0	110.78	0.74	278.46
4	1.0	7.37	0.51	216.91
5	1.0	135.91	0.34	273.03
6	1.0	295.22	0.58	83.27
7	1.0	312.95	0.93	120.76
8	1.0	196.25	0.11	94.03
9	1.0	0	0.16	338.46
SLL (in dB*)*	-15.70		-16.88	
Beamwidth (in degrees)	54		48	

5. References

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