Circular Array Pattern Synthesis using Particle Swarm Optimization

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ABSTRACT

In this paper a new and effective optimization algorithm is proposed known as Particle Swarm Optimization which is found to be more effective and faster than the GA techniques. The new approach determines an optimum set of weights and antenna element separations that provide a radiation pattern with reduced side lobe level with the constraint of fixed beam width. Results show that the method of particle Swarm Optimization yields results which are better than that obtainedby Genetic Algorithm.

Keywords: Particle Swarm Optimization, Circular Array**,**optimum weights, Beam width.

Introduction

In global synthesis of antenna arrays that generate a desired radiation pattern is a highly non-linear optimization problem. Pattern synthesis is the process of choosing the parameters of an antenna array to produce characteristics which are highly directional in nature. Analytical method fail to find optimum solutions with precedence constraint. To this end stochastic methods are necessary to deal with large non-linear search spaces and to extend the analysis [4].
Genetic Algorithms have proven to be useful method for optimization of difficult and discontinuous multi-dimensional engineering problems. A new Optimization Algorithm the PSO is able to accomplish the same goal in a new and faster way. The purpose of this paper is to investigate the foundation and performance of the two algorithms when applied to antenna array design.
Among the different type of antenna arrays, recently circular arrays have become most popular in mobile and wirelesscommunications. In this paper we proposed the use of PSO techniques to determine an optimum set of weights and antenna elementseparations for circular arrays that provide aradiation pattern with maximum side lobe levelreduction. First in section 2 the general designequation for circular antenna arrays are stated. Then in section 3 a brief introduction of thePSO algorithm is stated. In section 4 thefitness (or cost) function is given and finallynumerical results are presented in section 5.

Problem Formulation:

Consider circular antenna Array of N antenna elements. Non-uniformly placed on a circle of radius a in the x-y plane (fig. 1), the elements in the circular array are taken to be isotropic so the radiation pattern of the array can be described by the array factor.
In the x-y plane the array factor for the circular array is given by:-

$$AF(\varphi, I, d) = \sum_{n=1}^{N} In\ e^{j(ka\cos(\varphi-\varphi n)+\alpha n)}$$

$$Ka = \sum_{i=1}^{N} di, \qquad \varphi n = 2\pi/Ka \sum_{i=1}^{N} di$$

In the above equations, I_n and φn represents the excitation amptitude and phase of the n_{th} element and d_n represents the arc separation between element n and element n-1 and φn is the angular position of the nth element in the xy plane. To direct the excitation phase of the main beam in the $\varphi 0$ direction the excitation phase of the nth element is chosen to be:-

$$\alpha n = -Ka\cos(\varphi 0 - \varphi n)$$

In this case the array factor can be written as:-

$$AF(\varphi, I, d) = \sum_{n=1}^{N} In\ e^{-jka[\{\cos(\varphi-\varphi n)-\cos(\varphi 0-\varphi n)\}]}$$

In our design we choose $\varphi 0$ to be zero that is peak of the main beam is in the x direction:-

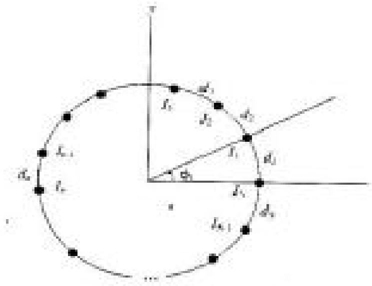

Fig. 1 : Geometry of a non-uniform circular antenna array with N isotropic radiators

The Particle Swarm Optimization

The method of PSO has been found to be useful for various optimization problems. Recently it has beensuccessfully applied to the design of antenna and microwave components. PSO is a robust stochasticoptimization technique based on the movement and intelligence of swarms. PSO applies the concept of Social interaction to problem solving. It uses a number of agents (particles) that constitute a swarm moving around in the search space looking for the best solution. Each particle is treated as a point in the N-dimensional space, which adjusts its flyingaccording to its own flying experiences well as the flying experience of other particles. Each particle keeps track of the coordinates in the solution space which are associated with the best solution (fitness) that has achieved so far by those particles. This value is called P-best (Personal best).

Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighborhood of that article. This value is called g-best. The basic concept of PSO lies in accelerating each particle towards its p-best and the g-best location, with a random weighed acceleration at each time step as show in figure 2.

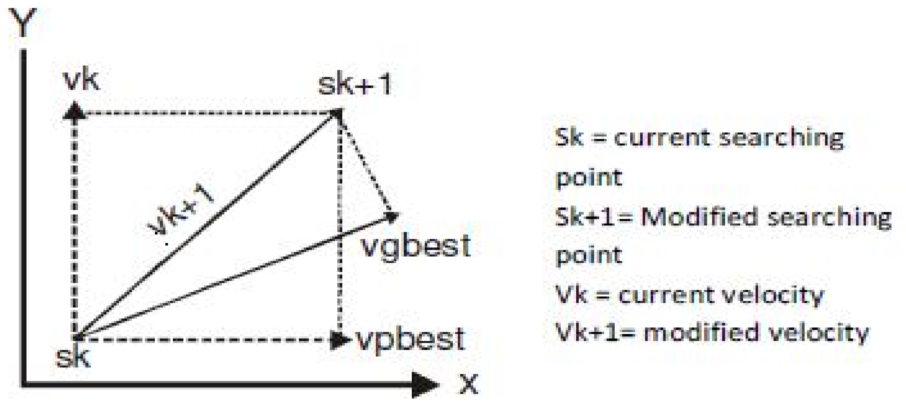

Fig. 2

Concept of modification of searching point by PSO.

Each particle tries to modify its position using the following information:-

The current position

The current velocity

The distance between current position and Pbest.

The distance between current position and Gbest

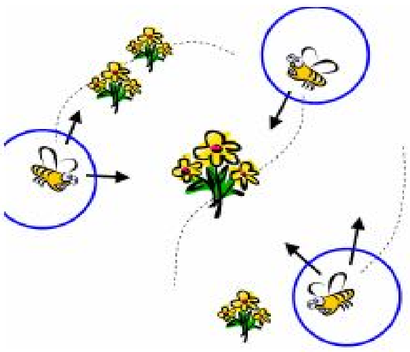

Fig 3 : Particle Swarm Optimization as modeled by|a swarm of bees searching for flowers

The update equation for particle velocity and position is:-

$$V_i^{k+1} = wV_i^k + C_1\, rand_1(\dots)X(pbest_i - S_i^k) + C_2\, rand_2(\dots)X(gbest_i - S_i^k)$$

V_i^k velocity of agent i at iteration k

w= weighing function

cj = weighing factor

rand = informly distributed random number

S_i^k= current position

The meaning of the R.H.S. of (1) can be explained as follows. The R.H.S. of (1) consists of three terms (vectors). The first termis the previous velocity of the agent. The second and third terms are utilized to change the velocity of the agent. Without the second and third terms, the agent will keep on flying in the same direction until it hits the boundary. Namely, it tries to explore new areas and therefore the first term corresponds to diversification in the search procedure. On the other hand, without the first term the velocity of the "flying" agent is only determined by its current position and its best position in history. Namely the agents try to converge to its pbest/gbest and therefore the terms correspondto intensification in the search procedure. As shown below for example wmax and wminare set to 0.9 and 0.2. Therefore at the beginning of the search procedure diversification is heavily weighted, while intensification is heavily weighted at the end of the search procedure.
The following weighing function is usually utilized in (1):-

$$w = w_{max} - [(w_{max} - w_{min})x\, iter]/maxiter$$

When w_{max} = initial weight

W_{min} = final weight

Maxiter = maximum iteration number

Iter = current iteration number

Thus the position is modified by the following equation:-

$$S_i^{k+1} = S_i^k + V_i^{k+1}$$

A large inertia weight factor constitute of global search which a small inertia weight facilitates a local search. By linearly increasing the inertia weight from a relatively large value to a small value through the PSO gives the best PSO performanceCompared with fixed inertia weight settings.

Fitness Function:

A Key point of optimization is the construction of the target function. In this paper the fitness function is to be minimizedfor array optimization problem can beexpressed as follows:

$$\text{Fitness}=1/\pi + \varphi nu1 \int_{-\pi}^{\varphi nu1} |AF(\varphi, I, d)| d\varphi + 1/\pi + \varphi nu2 \int_{\varphi nu2}^{\pi} |AF(\varphi, I, d)| d\varphi$$

Where φnu is the angle at the null. Here we denote the FNBW as $\varphi nu2 - \varphi nu1$

The fitness function signifies the minimization of the average side lobe level. Thus the optimization problem is to search for the current amplitude In and the arc distances d_n which minimize the above fitness function.

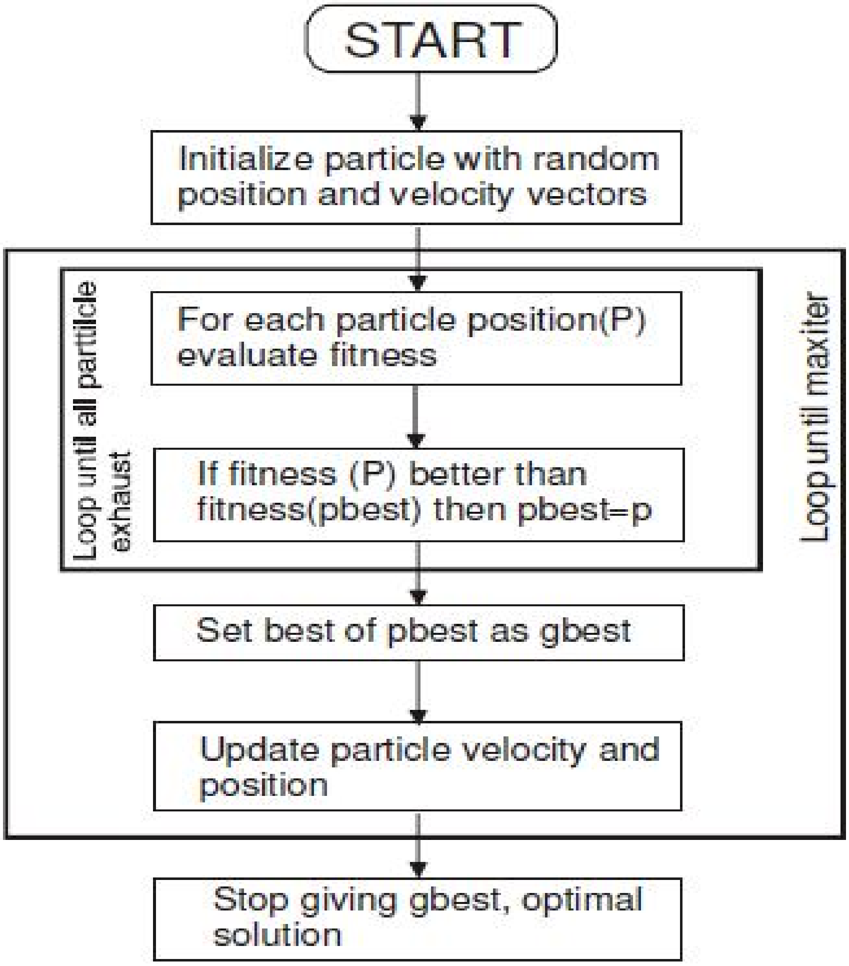

Fig. 4: Flow Chart depicting the general PSO algorithm

Results

Several cases were considered with different number of antenna elements. (N=8, 10, 12). The Swarm size used is 20-30. The number ofiteration used is 95-100. The experiments areperformed for a specific FNBW, whichcorresponds to a uniform circular array withuniform _/2 spacing and same number ofelements. Table 1 shows the results obtainedusing PSO. The array factor obtained using theresults of PSO will be compared with the arrayfactor obtained using genetic algorithm.

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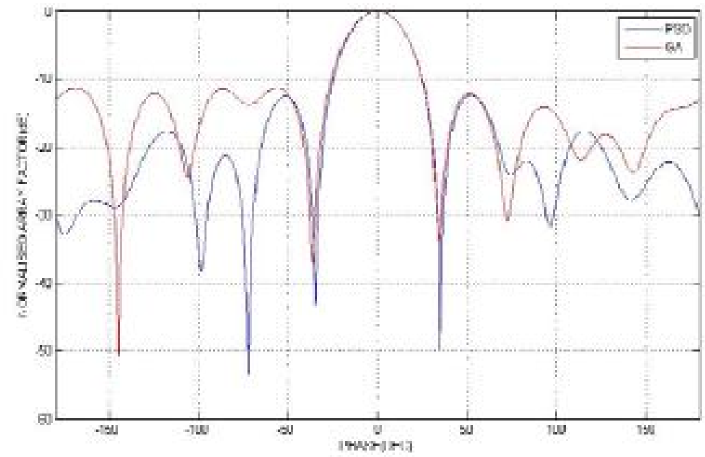

Fig. 5 Radiation pattern for N=8 using the PSO results as compared to the GA results from [4]

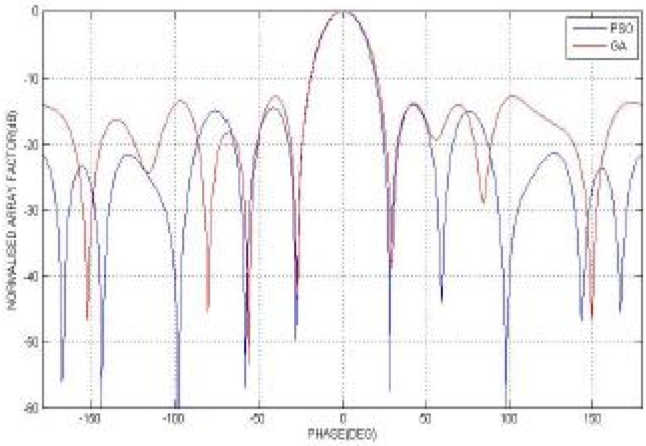

Fig. 6 Radiation pattern for N=10 using the PSO results as compared to the GA results from [4]

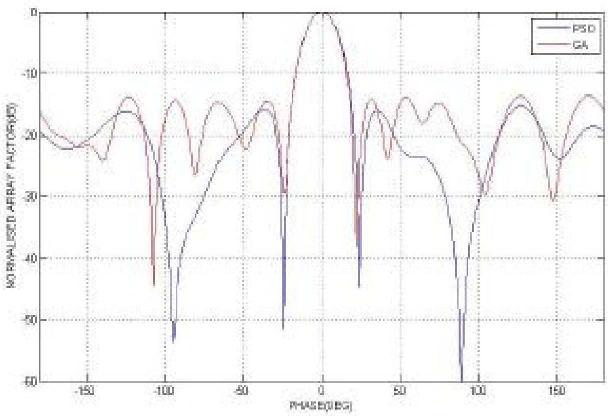

Fig. 7 Radiation pattern for N=12 using the PSO results as compared to the GA results from [4]

Table 1. Examples of non-uniform circular antenna Array optimized using PSO technique

N	FNBW (deg)	[dm1,dm2,dm3,………………,dmN] in λ's [I1,I2,I3,……………….IN]
8	70	[.3504,.5781,.2444,.7617,.6056,.8370,.7837,.3397,] [.7757,.3953,.6067,.8426,1,.7089,.9319,.3554] Σ=4.5006
10	55.90	[.3172,.9670,.3881,.9649,.3161,.3101,.9665,.3802,.9666,.3101] [1,.7509,.7505,1,.5039,1,.7547,.7544,1,.5042] Σ=5.8868
12	48	[.2520,.8517,.6659,.7065,.8574.3763,.1642,.8346,.6400,.7033,.8338,.2650] [.9562,.6644,.7179,.7761,1,1,.3963,.7197,.6706,.7664,.9307,.6496] Σ=7.1507

It can be seen that using the above fitnessfunction along with the PSO method gives theradiation pattern which is better than thatobtained from GA results. Specifically all side lobes except the first one adjacent to the majorlobe is –15dB.Similarly for N=10 as compared to the resultsobtained using GA the PSO array factor showsbetter symmetry around f=0.Similarly for N=12 the obtained results arebetter for PSO than for GA.The three cases shown in this paper shows anearly symmetric pattern in comparison to theresults presented in [4]. Such symmetry isusually desirable in many applications. It should be noted that for N=8 case the size ofthe circular array obtained using the PSO(circular circumference = 4.5006λ) is slightlylarger than that obtained using GA (circularcircumference = 4.409λ) [4]. On the otherhand N=10 case (circular circumference =5.8848λ) and for N=12 case (circularcircumference = 7.1507l) show better side lobe suppression with somewhat smaller sizethan that presented in [4] (6.0886λ and 7.77λ) respectively).

Conclusions

An optimization method for the synthesis ofcircular array pattern functions has beenproposed and assessed. Results clearly show avery good agreement between the desired andsynthesized specification for the non-uniformcircular case. Since this algorithm proposed inthis paper is reliable and effective and thisfeature makes it suitable for wider applicationin electro magnetics.

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JoyantoRoychoudhary received his M.Tech degree in Electronics and Communication Engineering from National Institute of Technology, Durgapur, West Bengal in 2009. Presently he is working as an Assistant Professor(Grade –III) in the Department of Electronics and Communication Engineering, B.P. Poddar Institute of Management and Technology in Kolkata. His Research interests are Soft Computing , Neural Networks and Spintronics.