Suppression of Antenna's Radiation Sidelobes Using Particle Swarm Optimisation

Nik Noordini Nik Abd Malik, **Mazlina Esa**,
Sharifah Kamilah Syed Yusof, **and Jayaseelan Marimuthu**
Faculty of Electrical Engineering, Universiti Teknologi Malaysia
81310 UTM Skudai, Johor, Malaysia

Abstract— The presence of large sidelobe radiation beam levels of an antenna is undesirable as the antenna performance and efficiency will be greatly degraded. Antenna structures especially in array arrangements have the capability to provide interference reduction, improvement of the channel capacity and expanding the range of a signal's coverage. In this paper, Particle Swarm Optimization (PSO) is utilized to optimize the inter-element position of even-element linear antenna arrays (LAA). The objective is to produce as close to desired radiation pattern as possible that exhibits sidelobe level (SLL) suppression. The PSO algorithm can be successfully used to locate the optimum element positions based on symmetric and even-element LAAs of isotropic radiators. The results obtained showed that the PSO algorithm is capable of finding the optimal solution in most cases with superior performance over conventional method.

1. INTRODUCTION

Numerous studies on antenna arrays have been widely applied in phase array radar, satellite communications and other fields. The array pattern of an antenna array should possess high power gain, lower sidelobe levels, controllable beamwidth [1] and good azimuthal symmetry. The desired radiation pattern of the antenna array can be realized by determining the physical layout of the antenna array and by choosing suitable complex excitation of the amplitude and phase of the currents that are applied on the array elements. Thus, evolutional optimization algorithm such as genetic algorithm (GA), simulated annealing (SA), and particle swarm optimization (PSO) have been introduced in antenna designs. Each algorithm has shown better performance due to its versatility, flexibility and capability to optimize complex multidimensional problem [2].

Currently, PSO algorithm is applied in many practical problems especially in electromagnetics. It has been used to obtain excitation coefficients of reconfigurable antenna arrays [3]; optimize the amplitude, phase, spacing and position of the elements in 37-element hexagon array [4] and suppress the SLL of linear array [5, 6].

In this paper, the PSO is exploited to produce the array radiation pattern that is nearest to the desired objective which exhibits sidelobe level (SLL) suppression and/or null placement. The inter-element position of even element linear arrays is optimized and re-located whilst maintaining uniform excitation over the array aperture. The work compliments [7] on node coordination.

2. LINEAR ANTENNA ARRAY SYNTHESIS

A one-dimensional symmetric LAA is assumed which is placed along the x-axis as depicted in Fig. 1. It has even number of elements up to N. Assuming uniform excitation of amplitude, $I_n = 1$ and phase $\beta_n = 0$, the array factor can be written as:

$$AF(\phi) = 2\sum_{n=1}^{N} \cos\left[kd_n \cos(\phi)\right]. \tag{1}$$

where k, I_n, β_n, ϕ, and d_n are the wavenumber $\beta = 2\pi/\lambda$, excitation amplitude, phase, observation angle, and location of the nth element from the reference node at the origin, respectively. PSO will explore for the optimum element positions, d_n by aiming at the target objective which reduces the problem of SLL suppression and/or null placement.

3. PARTICLE SWARM OPTIMIZATION METHOD

Consider a set of population or swarm of matrix X, with elements that are referred as particles or agents. Each particle represents possible solution in defined population size, S. For an N-

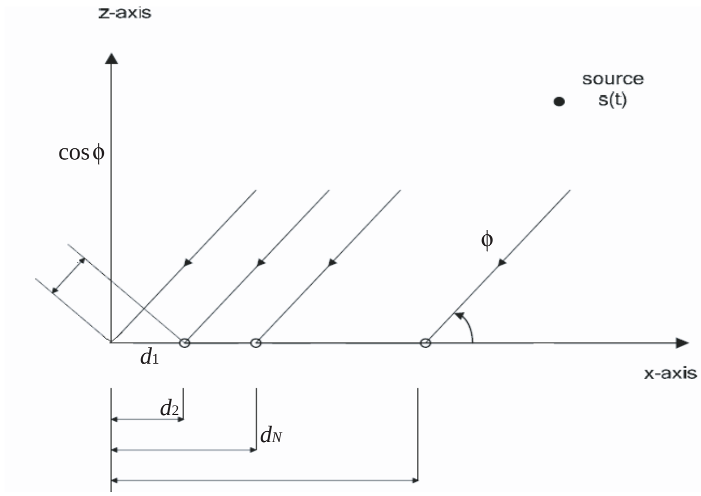

Figure 1: $2N$ linear array geometry.

dimensional problem, the position of the i-th particle ($i = 1, \ldots, S$) is represented as:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1N} \\ x_{21} & & & x_{2N} \\ \vdots & & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{iN} \end{bmatrix} \tag{2}$$

i.e., the position coordinates of the elements. x_{i1} is limited between two boundaries, U_1 and L_1, i.e., ($L_1 \leq x_{i1} \leq U_1$) and x_{iN-1} is limited between two other boundaries, U_N and L_N i.e., ($L_N \leq x_{iN-1} \leq U_N$). The i-th particle in the solution space is determined by fitness function value which depends on the position coordinates. Every time the value of the fitness function i.e., F is minimized, the particle position is improved. The best previous position, pbest of the i-th particle can be defined as position matrix for an individual particle's best fitness function, pbest:

$$P = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_i \end{bmatrix} \tag{3}$$

The global best position, gbest, is the position in the search space at which the best fitness function was achieved among all particles. It is defined as:

$$G = [g_1 \quad g_2 \quad \cdots \quad g_N] \tag{4}$$

Each particle should know its pbest and gbest. The positions and velocities of particles are then updated in each iteration according to the following equation:

$$v_{iN}(t+1) = wv_{iN}(t) + c_1 \mathrm{rand}(t)[p_i(t+1) - x_{iN}(t)] + c_2 \mathrm{Rand}(t)[g_N(t+1) - x_{iN}(t)] \tag{5}$$

where

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1N} \\ v_{21} & & & v_{2N} \\ \vdots & & \ddots & \vdots \\ v_{i1} & v_{i2} & \cdots & v_{iN} \end{bmatrix} \tag{6}$$

is the velocity matrix of the particles. The velocity of each particle depends on the distance of the current position to the position with the best fitness function. In Eq. (5), $(t+1)$ and t refer to the time index of the current and previous iterations, rand(t) and Rand(t) are functions that generate random numbers between 0.0 and 1.0. The parameters c_1 and c_2 are the relative weight of the pbest and gbest. It is selected as a value of 2.0 [5]. The parameter w is termed the inertial weight with value of 0.4. After time step, the new position of the particle is given by:

$$X(t+1) = X(t) + V(t+1) \tag{7}$$

The PSO is employed to optimize the optimum element position in order to improve the radiation pattern of the LAA, with $S = 30$. The objective of the algorithm is to find the gbest coordinates, G, that corresponds to the minimum value of the fitness function, $F_{\min}$ or $F(g_1, g_2, \ldots, g_N)$. The fitness function identifies how good the position vector of each particle satisfies the requirements of the optimization problem. The fitness function is computed using:

$$F = \sum_{s=i}^{s=j} |AF(\phi_s)|^2 + \sum_{n} |AF(\phi_n)|^2 \tag{8}$$

where s is the region where the SLL is suppressed and n is the angle where the nulls are placed. As the fitness function decreases, the radiation pattern improves with related particle's position x_{iN}. Therefore, when the fitness function discovers its optimized minimum value, the PSO algorithm will terminate successfully.

4. RESULTS AND DISCUSSION

A $2N$-element LAA with different numbers of elements and desired radiation pattern have been considered to assess the effectiveness of the PSO in the optimization. The LAA is assumed to be symmetric about the x-axis with uniform interelement spacing of $\lambda_0 = \lambda/2$. Initially, the particle position, X is randomly generated in the range of 0 to 1.5 to produce more diverse possible solutions. Some boundary conditions are also defined to d_n which is allowed to vary from $0.8\lambda_0$ to $1.5\lambda_0$ except for d_1 which is allowed to vary from $0.3\lambda_0$ to $1.0\lambda_0$. The applied parameters are: Swarm size, $S = 30$, particle size depends on the problem dimension, c_1 and c_2 equal to 2.0, internal weight $w = 0.4$. The particles are represented by the spacing between the neighbor elements.

Case 1. A 14-element LAA is simulated for SLL suppression. The element positions for both conventional and PSO methods are given in Fig. 2 which is symmetrical by the y-axis. The radiation pattern is presented in Fig. 4. It is clearly seen that the PSO algorithm provides improvement to the SLL suppression. Almost all sidelobes have been minimized particularly the first SLL and far sidelobes.

Case 2. A 10-element LAA is designed for null placement at 76° and 104°. Fig. 5 shows that deep nulls of −58 dB have shown in Fig. 4. From Fig. 5, it can be inferred that larger beamwidth is obtained by using PSO because of the null placement at the desired angle. In addition, there are also decrements of all SLLs. The total length of the element by using PSO has increased to merely 4.2 which is less than that of the conventional method as in Fig. 4.

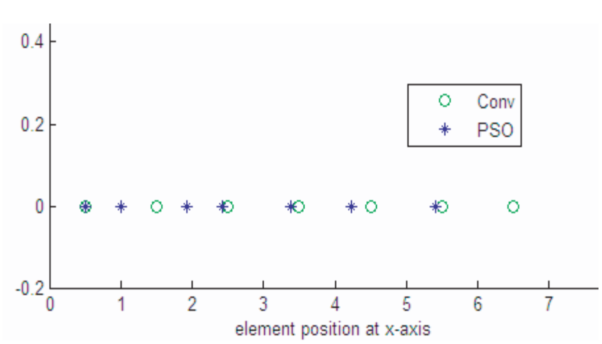

Figure 2: Element position of the 14-element LAA using PSO and conventional methods. Numbers are normalized wrt $\lambda_0 = \lambda/2$.

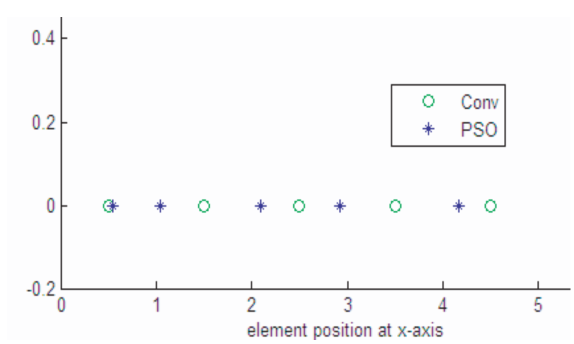

Figure 3: Element position of the 10-element LAA using PSO and conventional methods. Numbers are normalized wrt $\lambda_0 = \lambda/2$.

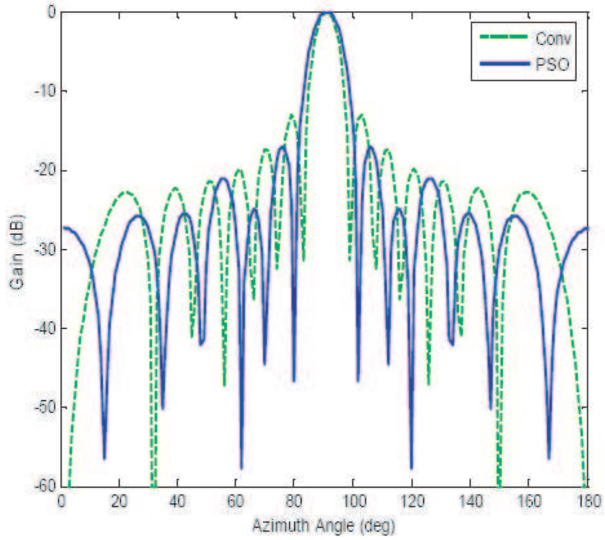

Figure 4: Radiation patterns of 14-element LAA by using PSO and conventional methods. SLL suppression at (0°, 80°) and (99°, 180°).

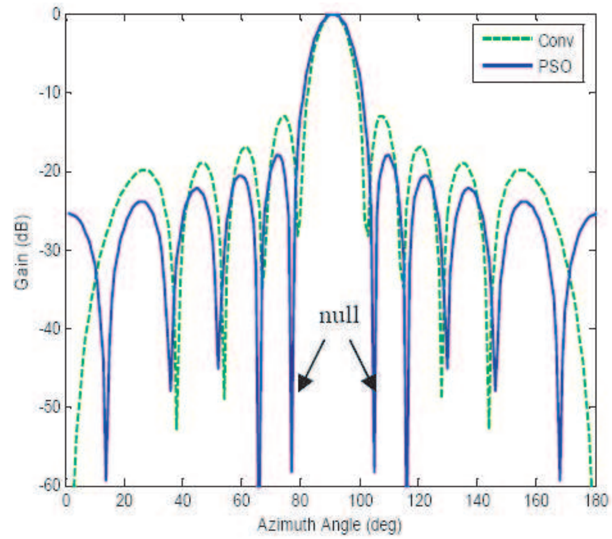

Figure 5: Radiation patterns of 10-element LAA by using PSO and conventional methods. The null placement are at 76° and 104°.

5. CONCLUSION

The PSO algorithm has been shown to successfully improve the radiation pattern of the LAA as desired. All the design requirements of the radiation pattern simulation for the LAA is presented and highly satisfied. The developed PSO algorithm has successfully optimized the position of the array elements to demonstrate a radiation pattern with either suppressed SLL, null placement, or both.

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