A MODIFIED DIFFERENTIAL EVOLUTION ALGORITHM IN SPARSE LINEAR ANTENNA ARRAY SYNTHESIS

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ABSTRACT

A modification on the classical Differential Evolution (DE) algorithm, based on randomization of the mutation scale factor, is proposed in the linear antenna array synthesis. An example of position-phase synthesis of unequally spaced linear antenna array with the minimum peak sidelobe level is presented and compared with some published results. The comparison clearly indicates that the proposed modification outperforms the existing results in the recent literature obtained by variants of DE algorithm.

Keywords: Differential Evolution, Antenna Array, Sidelobe Suppression.

INTRODUCTION

There has been an increasing focus on antenna array design due to the increase both in size and in the variety of wireless applications. One of the main objectives of array design is beam shaping of the radiation pattern by adjusting parameters such as geometrical configuration, relative displacements, excitation amplitudes, excitation phases and relative patterns of identical elements (Balanis, 1982). In some design problems, such as when a very high directivity is required in the selected direction, analytical techniques cannot give adequate results. Thus, it is required to embed some numerical optimization techniques into the design process.

In this paper, a simple and effective modification on the classical DE algorithm is proposed and is applied for the position-phase synthesis of the linear antenna arrays. The obtained results are compared with the results of some variants of the DE algorithm obtained from the recent literature (Kurup et al., 2003), (Lin & Qing, 2010) and (Goudos et al., 2011).

CONTEXT AND REVIEW OF LITERATURE

The Differential Evolution is one of the evolutionary algorithms that extensively applied for synthesizing of antenna arrays and some other electromagnetic problems (Rocca et al., 2011). Differential evolution (DE) algorithm was proposed by Price and Storn in 1995 (Storn & Price, 1997), (Price et al., 2005). It is an effective, robust and simple global optimization algorithm which has a few control parameters.

The DE algorithm is used in antenna array synthesis problems extensively. A classical DE algorithm is used in synthesizing unequally spaced antenna arrays in (Kurup et al., 2003). Dynamic Differential

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Evolution (DDE) algorithm (Qing, 2006), which differs from the DE algorithm by the strategy used for updating individuals, is applied to antenna synthesis problems in (Lin & Qing, 2010). The effect of angular resolutions which are used to span the space in optimization has also been investigated in (Lin & Qing, 2010).

A modified version of the DDE algorithm, which is called Modified Differential Evolution Strategy (MDES), is also applied to some antenna synthesis problems (Chen et al., 2008). Another variant of the DE algorithm, which adaptively adjusts the control parameters, is Self Adaptive Differential Evolution (SADE) algorithm (Brest et al., 2006). The SADE algorithm is also applied to some antenna and microwave design problems (Goudos et al., 2011).

METHOD

Sidelobe Suppression of Antenna Arrays

We consider an array of 2N isotropic antennas, which are placed symmetrically along the x-axis, as shown in Fig. 1. The radiation pattern of the given array is symmetric with respect to the x-axis. The array factor AF is a function of the angle θ, which represents the angular separation from y-axis and it can be written as follows (Balanis, 1982), (Lin & Qing, 2010),

$$AF(\mathbf{x},\mathbf{I},\boldsymbol{\phi},\theta)=\sum_{i=\;N}^{N} I_i \exp\left(2\pi\frac{x_i}{\lambda}\sin(\theta)+\varphi_i\right) \qquad (1)$$

where λ is the wavelength and three vectors, x, I and ϕ, contain the positions, excitation currents and excitation phases of the antenna elements. The array factor is a function of only the angle θ for a synthesized antenna array in which x, I and ϕ are determined.

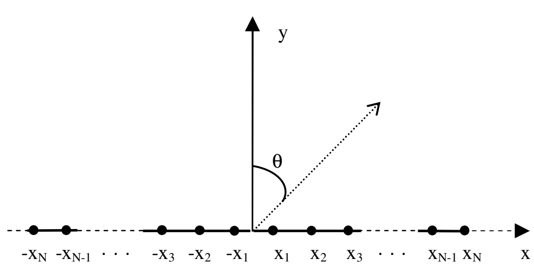

Figure 1. Geometry of the 2N element symmetric linear antenna array along the x-axis

The peak sidelobe level (PSLL) of the antenna array is defined as (Lin & Qing, 2010)

$$PSLL(\mathbf{x},\mathbf{I},\boldsymbol{\phi})=\max_{\forall\theta\in S}\left\{\frac{AF(x,I,\varphi,\theta)}{AF(x,I,\varphi,0)}\right\} \qquad (2)$$

where S is the space spanned by the angle θ excluding the predefined main lobe with the center at θ=0. The objective function is selected to minimize PSLL, since the focus of array synthesis of our work is to minimize the peak sidelobe levels of the unequally spaced antenna arrays with uniform amplitude excitation. We consider the position-phase synthesis that the excitation currents are the same for all elements (i.e. $I_{-i}=I_i=1$, for i=1, 2, 3, …, N) and elements are assumed to be symmetric (i.e. $x_{-i}=x_i$, and $\phi_{-i}=\phi_i$ for i=1, 2, 3, …, N).Then, N couples of real numbers (x_i, ϕ_i ; i=1, 2, 3, …, N), where x_i is the position and $\phi_i \in [0,\pi/2]$ is the phase of the ith element are forming the solution space.

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Differential Evolution Algorithm

The DE algorithm is a stochastic, parallel direct search method. It can be briefly stated as follows: Initialization: Initialize the population of size P in N dimensions.

Mutation

In each generation G, each N-dimensional solution (parent) vector z_i^G, i=1, 2…P is mutated to obtain the perturbed (mutant) vector v_i^{G+1} that is produced by

$$v_i^{G+1} = z_{r_1}^G + F.(z_{r_2}^G - z_{r_3}^G) \tag{3}$$

where r_1, r_2, r_3 are three mutually different integers, which are randomly chosen from the set {1,2, …, P}. They are also different from the value i. Mutation scale parameter (F) is a real constant number which has a control on the amplitude of the difference $(z_{r_2}^G - z_{r_3}^G)$.

Crossover

The crossover operator is mainly applied in order to increase the diversity of the mutant vector. In this step, the parent vector z_i^G together with the perturbed vector v_i^{G+1} are recombined to obtain the trial vector y_i^{G+1}.

Selection

In the selection phase, the fitness of the trial vector y_i^{G+1} is calculated and it is compared with the fitness of the parent vector z_i^G. If the fitness of the trial vector is better than its parent vector, then the trial vector replaces the parent vector in order to advance to the next generation. Otherwise, the parent vector is kept in the next generation without any change.

Proposed Modification on DE Algorithm

In the modified DE algorithm, the only change is performed on the selection of F value. Instead of selecting the F as a real and constant value, it is selected randomly by generating a uniform random number Fij$\in$[0, 1], where j=1, 2, …, N and i=1, 2, …, P. This random selection of F enables the algorithm to delve the region more deeply hence not stacking to local solutions.

NUMERICAL RESULTS

The modified DE algorithm is applied in the position-phase synthesizing of a 32-element linear array. The population size of the modified DE algorithm is set to 60. Crossover rate is set to 0.95. We run the program for 30 times for each problem and the best solution sets are presented and compared with published results.

Table 1. Comparison of the Best PSLL's obtained by Variants of DE Algorithms in dB

	Phase-Position	
	Recalculated	Reported
This Paper	-23.6508	
DE [3]	-23.2181	-23.34
DDE [7]	-23.5726	-23.45
SADE [10]	-23.3462	-23.59
MDES [8]	-23.1259	-23.45

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For each run, 3000 iterations are carried out. We set the desired beamwidth to 6.3°. The angular resolution is set to 0.2° which is also suggested in (Lin & Qing, 2010). The minimum and the maximum distances between any adjacent elements are set to 0.5λ and λ, respectively. In order to compare our results with the ones that are published in literature on the same basis, all PSLLs are recalculated with an angular resolution of 0.0018° (=π/100000) by using the positions and phases given each reference. The recalculated and the reported best PSLLs are given in Table I.

It should be noted that even the average PSLLs for the 30 runs with the modified DE algorithm, which is calculated as -23.6218 dB, is better than all the reported results. The standard deviation of PSLLs of 30 runs is calculated as 0,037659 dB, which clearly shows how robust the modified DE is for the analyzed problem. The best solution set, which is obtained by the proposed DE algorithm, is given in Table II.

Table 2. The Best Solution Set Obtained by the Proposed DE Algorithm

No	Position (x_i/λ)	Phase (Degrees)
1	0.250	41.84
2	0.750	42.13
3	1.250	45.47
4	1.750	42.92
5	2.250	47.29
6	2.754	44.25
7	3.314	44.11
8	3.864	42.96
9	4.509	42.52
10	5.098	42.64
11	5.751	44.06
12	6.560	37.85
13	7.429	40.05
14	8.268	72.41
15	9.242	12.60
16	10.114	40.72

The first three sidelobes of the best synthesis of the proposed DE algorithm are compared with the best solution sets of DDE (Lin & Qing, 2010) and SADE (Goudos et al., 2011) algorithms in Fig. 2. It can be observed that the obtained solution set by using the modified DE algorithm outperforms the best solution sets, which were presented in (Lin & Qing, 2010) and (Goudos et al., 2011).

DISCUSSION AND CONCLUSION

The proposed modification on the DE algorithm aims to construct a deeper search in the region of interest. The experiments that we have conducted have shown us that this modification of the DE algorithm does not only improve the solution quality, but also increases the robustness of the algorithm when it is applied to the selected antenna synthesis problems. Moreover, we observe that the randomization of the mutation scale factor is very effective in the problems that have many local minimums in the region of interest.

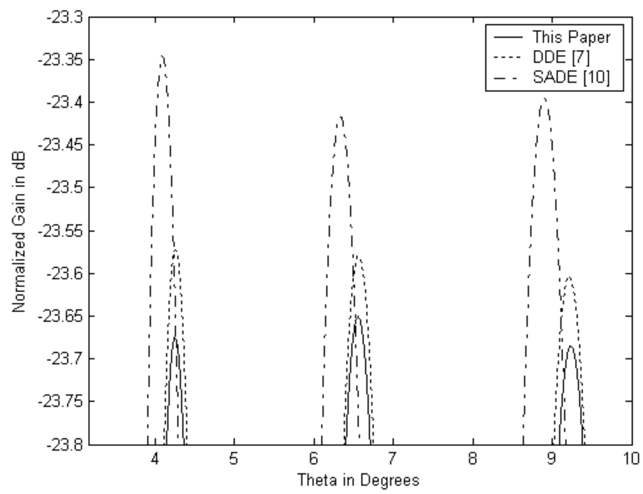

Figure 2. The first three sidelobes of position phase synthesis of 32-element linear array obtained by using different DE algorithms.

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