On The Beam Forming Characteristics of Linear Array Using Nature Inspired Computing Techniques

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Abstract ─ Beamforming is a serious problem in wireless communication. Many deterministic and numerical techniques are proposed to achieve beamforming. However, the application of evolutionary computing techniques produced better results over many existing conventional methods. In this paper, one such attempt of applying a novel nature-inspired technique known as Firefly algorithm (FFA) to demonstrate beamforming in linear arrays and compared with particle swarm optimization (PSO). The desired objectives of the synthesis process are defined as sidelobe level (SLL) suppression and null positioning. The optimal set of amplitude distribution for the elements in the linear array is obtained using the technique in order to achieve the desired objectives. The results are evaluated in terms of radiation pattern plots.

Index Terms ─ Antenna array, Firefly algorithm, particle swarm optimization.

I. INTRODUCTION

Beamforming, on one hand it involves in observing deep nulls in the direction of the undesired signal and, on the other hand, it involves in positioning the main beam in the direction of the desired signal. Antenna array which have perfect control of radiation characteristics like sidelobe level (SLL), control on beam width (BW) along with beam steering (BS) capabilities have emerged as the best candidates for beamforming applications [1]. Linear arrays are the simplest form of array antenna geometry. All the elements of the array are oriented along a straight line defined in terms of array length and number of elements. These linear arrays are the best candidates for beamforming applications with efficient sidelobe level suppression [2-4] and null control [5] characteristics. These arrays are capable of interference suppression through beam-forming technique. Nulls are located in the direction of arrival (DOA) of the interference signal while the main beam is steered to the DOA of the desired signal in order achieve the above said characteristics. Many conventional techniques are proposed to solve the problem of beamforming. Unfortunately, these are time-consuming as well as provide poor performance. In order to overcome these hurdles, in the recent past several evolutionary techniques are proposed [3-6]. These techniques are quite efficient and often express the supremacy over traditional techniques.

In this paper, novel nature-inspired metaheuristic evolutionary computing algorithm known as Firefly algorithm (FFA) [6, 7] is employed to achieve the specified two objectives of SLL suppression and null position in linear arrays. The rest of the paper is organized as follows. Sections 2 and 3 are dedicated to description of the problems statement and formulation of cost function. Implementation of the algorithm for the proposed problem is given in Section 3. The case wise presentation of results is given in Section 4 which is followed by overall conclusion in Section 5.

II. PROBLEM STATEMENT

The problem statement can be considered as to determine the amplitude distribution of linear array which produces the desired radiation pattern. The geometry of the broadside linear array of N equi-spaced isotropic elements with symmetric excitation positioned along Z-axis is shown in Fig. 1.

Mathematically, the array factor can be stated as:

$$E(\theta)=\sum_{n=1}^{N} I_n \exp\left[j(n-1)(kd\cos\theta+\beta)\right]. \qquad (1)$$

Here, x_n is Amplitude of excitation of the nth element of the array, k is wave number, d is spacing between the elements (λ/2), β = $kd\cos\theta_d$ and θ_d = Scan angle and

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N = Number of elements in the array. Progressive phase β is zero as pattern maxima is directed towards $\theta_d = 90^0$ for broadside linear array. However, in scanned array pattern maxima is oriented at an angle θ_d .

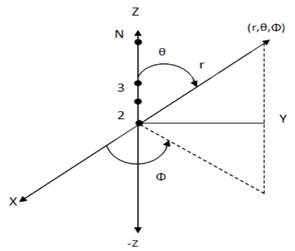


Fig.1. Geometry of broadside linear array.

III.COST FUNCTION FORMULATION

The two objectives considered in this work corresponding to linear array synthesis are SLL suppression and null positioning. The cost functions corresponding to these two objectives are given as below.

For SLL optimization:

$$f1 = \max[E_{\Theta=FN\ to\ \pi/2}]$$
$$cf1 = |f1-40| \quad \text{if } f1<40$$
$$= 0 \quad \text{otherwise,} \qquad (2)$$

where cf1 is cost function and FN is first null.

For null positioning:

$$E_{nmax} = \max[E_{(\Theta=n1)}, E_{(\Theta=n2)}, E_{(\Theta=n3)}]$$
$$cf2 = |E_{nmax}-60| \quad \text{if } E_{nmax}<60$$
$$= 0 \quad \text{otherwise,} \qquad (3)$$

where n1, n2 and n3 are desired null positions in degrees.

IV. OPTIMIZATION ALGORITHMS

A. Firefly algorithm

Genesis

FFA is proposed by Yang [6]. Like several other swarm intelligence based algorithms, FFA is also inspired by the natural behaviour of fireflies and the phenomenon of bioluminescent communication. Firefly species produce short and rhythmic flashes. These flashes of light play a vital role in bioluminescent communication. Mostly the flash pattern is unique for every species in terms of frequency, colour and time for which the flash of light is generated. These patterned flashes are used by the fireflies to attract other fireflies for mating. According to inverse square law the intensity of light at a certain distance r from the light source. Which means that the intensity of the light I goes on decreasing as the distance r increase in terms of $I \propto 1/r^2$. In addition to this another phenomenon known as absorption, the light becomes weaker as it travels along the distance. Due to these factors when combined make most fireflies visible at a limited distance, normally to a few hundred meters at night, which is quite enough for fireflies to communicate with each other. The following are the rules that are used to describe the structure of the FFA:

1) All fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex.
2) Attractiveness depends on the brightness of the flashed light. Accordingly, firefly with brighter flash is supposed to have good attractiveness than the firefly with less brightness.
3) Brightness is defined by the objective function or the landscape of the species.

Algorithm Construction

The construction of the algorithm considers several base rules which mimic the actual behaviour of the fireflies. It is interesting to note that these fireflies (FF) are unisex and are capable of drawing the attention of any companion FF. The degree of attraction is referred as individual's brightness. The brightness or light intensity of a firefly is influenced by the landscape of fitness/cost function. The basic steps of the FA can be summarized as the pseudo code in Fig. 2.

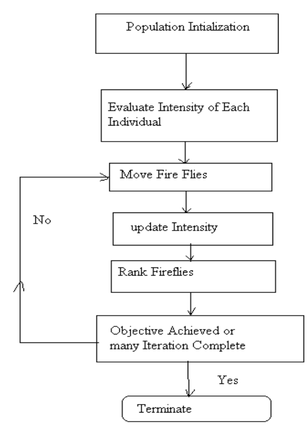


Fig. 2. Flowchart of Firefly algorithm.

Implementation of FFA for LA Synthesis

The adoption of the algorithm for the array synthesis problem starts with population initialization. Every individual FF in the population is considered as a respective array and the amplitude distribution for each array in the population is randomly generated. If P individual FF are considered, then the population is a vector of size 1xK. However, each individual FF is again a vector of size equal to the number of elements in each array. For example, the ith FF is given as follows:

$$x_i = [x_1, x_2, x_3 \ldots x_K], \qquad (4)$$

Similarly, the population matrix is given as:

$$X = \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_P \end{bmatrix} = \begin{bmatrix} x_{11}\ x_{12} \ldots x_{1K} \\ x_{21}\ x_{22} \ldots x_{2K} \\ . \ . \ . \ . \ . \ . \ . \\ . \ . \ . \ . \ . \ . \ . \\ x_{P1}\ x_{P2} \ldots x_{PK} \end{bmatrix}. \qquad (5)$$

After the population initialization the immediate step if FF evaluation, which means to evaluate the fitness of the FF and the corresponding amplitude distribution:

$$I_i = \text{ObjFunc}(x_i). \tag{6}$$

The calculation of the attractiveness of an FF is given by:

$$\beta(r) = \beta_o * \exp(-\gamma r_{ij}^2). \tag{7}$$

Here, r is the distance between any two fireflies, β_o is the initial attractiveness at r=0 and γ is the absorption coefficient which controls the decrease of the light intensity. The distance between any two fireflies i and j at x_i and x_j respectively can be defined as a Cartesian distance 'r_{ij}' using the following equation:

$$r_{ij} = |x_i - x_j| = \sqrt{\sum_{k=1}^{n} (x_{ij} - x_{jk})^2}. \tag{8}$$

The movement of a firefly 'i', which is attracted by a more attractive (i.e., brighter) firefly 'j' is given by the following equation:

$$x_i = x_i + \beta_o * \exp(-\gamma r_{ij}^2) * (x_j - x_i) + \alpha * (\text{rand} - 1/2). \tag{9}$$

B. Particle swarm optimization

PSO is developed by Kennedy and Eberhart and applied to several engineering problems. PSO belongs to the class of population based optimization technique which is inspired by social behaviour of bird flocking or fish schooling. The population in PSO constitutes particles. Each particle refers to the position in the search space. Every particle is subjected to move around the search space in search of the target and updates in every iteration. The displacement is governed by both velocity and position of the particle. The velocity depends on personal best position and the global best position of the particle. Personal best refers to the best position of the particle from the displacement history of the particle, while the global best refers to the best position among the flock in the current iteration. This is mathematically modelled using the following equation:

$$v_{k+1}^i = w v_k^i + \frac{\beta * rand(p^i - x_k^i)}{\Delta t} + \gamma * \frac{rand(p_k^g - x_k^i)}{\Delta t}, \tag{10}$$

$$x_{k+1}^i = x_k^i + \Delta t * v_{k+1}^i$$

v_k^i = velocity of i^{th} particle in the kth iteration, p_k^i = personal best of i^{th} particle in the kth iteration, p_k^g = global best in the kth iteration, w = inertial weight, β and α are cognitive and communal coefficients. In this case both are equal to 0.5.

V. RESULTS AND DISCUSSION

The simulation based experimentation is carried out for two different objectives. As discussed earlier, one of the objective is to obtain very low SLL than uniform distribution under scanned and un-scanned beam conditions. Un-scanned beam refers to position of main beam at 0^0 while scanned beam refers to main beam positioned at 30^0. In both the cases, the SLL is maintained well below the level observed with uniform distribution in which all the elements in the array are uniformly excited. Suppressed SLL to -40 dB is achieved by applying FFA to obtain non-uniform amplitude distribution. The results pertaining to this discussion are mentioned in Fig. 3. The pattern with dashed line refers to uniform distribution where the SLL is -13 dB while the solid line and dotted line refers to un-scanned and scanned radiation patterns with non-uniform distribution using FFA respectively.

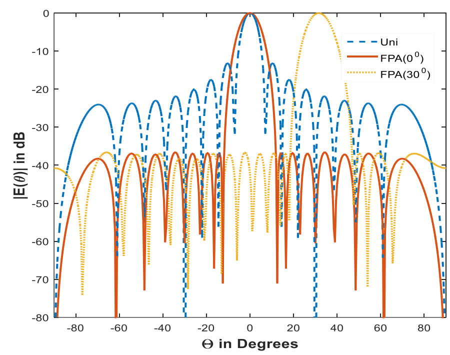
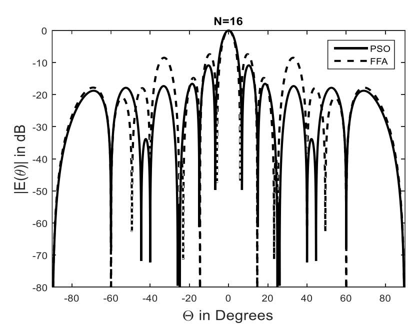
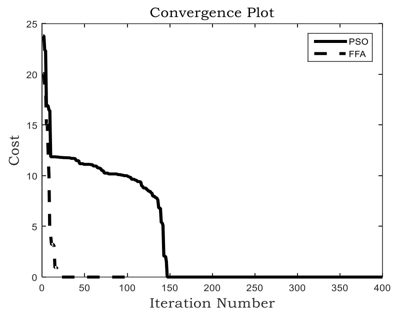


Fig. 3. SLL suppression in unscanned and scanned patterns.

As a second objective the problem of null positioning is considered for both unscanned and scanned beams. As a frst case in this objective, multiple nulls with fixed main position at 0^0 using both PSO and FFA is considered. The DOA of the interference signals are -25^0, 40^0 and 60^0. This is demonstrated in terms of radiation pattern in Fig. 4 (a) and the corresponding convergence plots in Fig. 4 (b). The amplitude distribution obtained using the FFA and PSO is given in the corresponding column of Table 1. As a second case beamsteering along with three nulls is considered. This is shown in the Fig. 5 (a), where the main beam is scanned to an angle of 30^0 which is considered as the DOA of the desired signal. The respective convergence plot is as shown in Fig. 5 (b). The corresponding amplitude distribution using PSO and FFA are as given in Table 1.

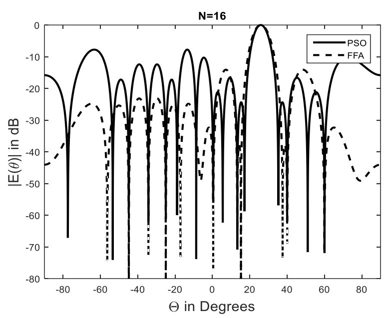


(a)

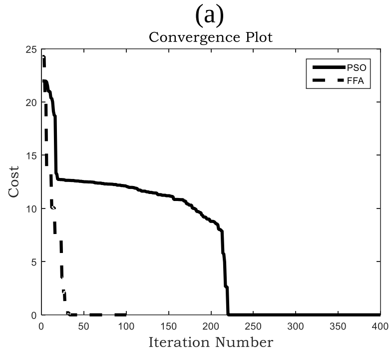


(b)

Fig. 4. (a) Radiation pattern with nulls at -25^0, 40^0 and 60^0 while main beam positioned at 0^0, and (b) convergence plot for PSO and FFA.



(a)



(b)

Fig. 5. (a) Radiation pattern with nulls at -25^0, 40^0 and 60^0 while main beam positioned at 25^0, and (b) convergence plot for PSO and FFA.

Table 1: Amplitude distribution obtained using FFA for different cases

Element Number	Amplitude Distribution					
	Fig. 3		Fig. 4		Fig. 5	
	0^0	30^0	FFA	PSO	FFA	PSO
1&1'	0.76	0.80	0.54	0.76	0.99	0.47
2&2'	0.72	0.76	0.04	0.36	0.86	0.57
3&3'	0.64	0.68	0.11	0.56	0.56	0.14
4&4'	0.53	0.56	0.77	0.75	0.41	0.38
5&5'	0.41	0.44	0.71	0.75	0.48	0.50
6&6'	0.29	0.31	0.46	0.85	0.59	0.13
7&7'	0.18	0.20	0.60	0.55	0.37	0.00
8&8'	0.13	0.15	0.85	0.73	0.38	0.68

VI CONCLUSION

FFA has been successfully applied to array synthesis problems in beamforming applications with multiple objectives. The technique of generating nulls in the desired directions in order to suppress the interference signals is well demonstrated under un-scanned and scanned conditions for beamforming characteristics. FFA has shown its efficiency and simplicity in terms of computation time and complexity. It is evident from the plots that the convergence is achieved earlier with FFA than PSO in all the cases mentioned above. Moreover, the convergence is delayed when the beam is scanned to a certain angle. The technique demonstrated in this paper can easily be extended to any multimodal problems with several constraints.

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