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Synthesis of linear aperiodic array using Cauchy mutated cat swarm optimization

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ABSTRACT

A novel Cauchy mutated cat swarm optimization (CMCSO) that features effective global search capabilities with fast convergence is introduced in this paper. The Cauchy mutation enables the cats of the cat swarm optimization (CSO) algorithm to seek their positions in directions that avoid the problem of premature convergence and local optima. In this communication, CMCSO is applied to the synthesis of linear aperiodic arrays for minimizing sidelobe level and controlling the null positions. Various synthesis examples are considered and the obtained results are compared with linear aperiodic array designs from literature. Numerical results demonstrate that the proposed method is superior to existing methods in terms of accuracy and convergence speed. Some of the synthesized aperiodic array designs are implemented with wire dipole antenna elements using a full-wave electromagnetic simulator. Furthermore, experiments are conducted on several standard benchmark complex multimodal problems to demonstrate the effectiveness of the proposed method. The sensitivity analysis is performed on different parameters of CMCSO to demonstrate their influence on the overall performance of the benchmark and antenna array synthesis problems.

1. Introduction

Antenna arrays are being widely used in wireless, satellite, mobile and radar communications systems. They help in improving the system performance by enhancing directivity, improving signal quality, extending system coverage and increasing spectrum efficiency. The performance of the communication system greatly depends on the efficient design of the antenna arrays. Systems need to maintain low peak side lobe level (PSLL) to avoid interference with other systems operating in the same frequency band. Also, the increasing EM pollution has prompted the placing of nulls in undesired directions. So it is necessary to design the antenna array with low side lobe levels while maintaining fixed beam width and placing of nulls in desired directions.

For the linear array geometry, suppressing sidelobe levels and placing of nulls in desired directions can be achieved in two ways, either by optimizing the spacings between the element positions while maintaining uniform excitations or by employing non-uniform excitations of the elements while using periodic placement of antenna elements. But practical implementation of non-uniform complex weights in periodic arrays is difficult. Instead, non-uniform spacing of elements resulting in aperiodic arrays provides greater flexibility in controlling the shape of the radiation pattern without disturbing the uniform feeding network. The aperiodic antenna array can be obtained by aperiodic spacing of the elements or by thinning the array by turning off the elements.

Unequally spaced arrays can be produced by shifting the geometric positions of the antenna elements (non-uniform antenna element spacings) of a periodic array as illustrated in Fig. 1. In unequally spaced array, the total number of antenna elements remains the same as in the periodic array but the antenna array aperture length may vary depending on the configuration adopted. The non-uniform spacing in antenna array helps in eliminating grating lobes, making the unequally spaced array a prime candidate for wide bandwidth scanning applications.

Aperiodic array has gained a lot of attention because of its simple feeding network. Aperiodic linear antenna array synthesis has been extensively studied for the past 5 decades [1–18]. It involves non-convex and non-linear optimization. In order to optimize this type of electromagnetic design problems, evolutionary algorithms such as genetic algorithm (GA) [3–7], differential evolution (DE) [8–12], particle swarm optimization (PSO) [13–15], ant colony optimization (ACO) [16] have been successfully applied. All the above mentioned evolutionary algorithms have shown the capability of

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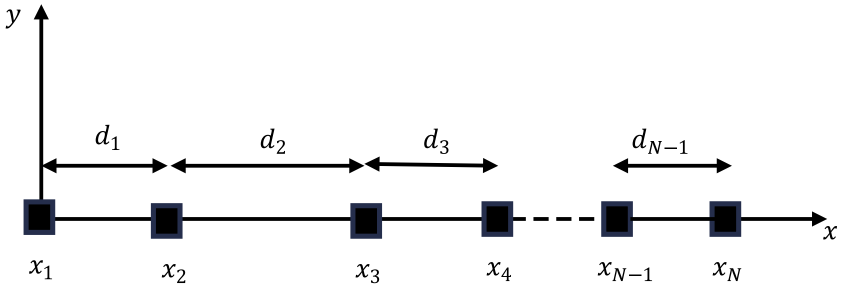

Fig. 1. Illustration of non-uniform spacing linear antenna array.

searching for the global solution in electromagnetic optimization problems.

CSO is a high-performance computational method, inspired by the natural behavior of cats. It was introduced by Chu and Tsai in 2007 [19]. It has been applied to different engineering problems [20,21] and has shown better performance over well-known algorithms.

But the classical CSO suffers from premature convergence and gets easily trapped in the local optima because of the random mutation process while updating the cat's position. This frailty has restricted the wider range of application of the classical CSO. The choice of mutation process type has a strong influence on convergence behavior of CSO. To overcome the drawbacks, the Cauchy mutation strategy [22–24] is proposed for the position updating process of the CSO algorithm. The introduction of this operator enhances the convergence rate and solution accuracy of the CSO algorithm in solving complex multimodal problems. In this paper, Cauchy mutated CSO (CMCSO) algorithm is applied to optimize the element positions in a linear aperiodic array to control the shape of the radiation pattern in terms of minimum PSLL with null positioning in desired directions.

The major contributions of this paper are given below.

(a) This paper presents a new novel version of classical CSO. CMCSO has numerous benefits. The two most important goals such as the faster convergence rate and avoiding the local optima in a complex environment can be achieved by the proposed method. It can be applied to solve not only single objective problems but also multi-objective problems.
(b) This paper presents the application of the proposed CMCSO to aperiodic linear antenna array synthesis with sidelobe level suppression and null control.
(c) This paper presents a comprehensive comparison of CMCSO with the popular state of the art algorithms.
(d) This paper addresses the implementation of the synthesized aperiodic array design with wire dipole antenna elements using high-frequency structure simulator (HFSS).

The paper is organized as follows. The configuration of the linear array is discussed in Section 2. Section 3 presents a detailed description of the classical CSO and proposed CMCSO algorithm. Numerical results of synthesis of symmetric aperiodic linear arrays are presented in Section 4. Section 5 presents the validation of the synthesized aperiodic arrays with real antenna elements using HFSS. The sensitive analysis of different parameters of CMCSO on the chosen problems are presented in Section 6 and lastly, Section 7 highlights the achievements of this research work.

2. Linear antenna array

The geometry of a uniformly excited periodically placed linear antenna array with M elements placed along x-axis is illustrated in Fig. 2. The antenna array factor (AF) in the azimuth plane M = 2N and M = 2N + 1 can be expressed as

$$\mathrm{AF}(\mathbf{X},\theta) = 2\sum_{n=1}^{N}\cos[kx_n\cos(\theta)];\quad M = 2N \tag{1}$$

$$\mathrm{AF}(\mathbf{X},\theta) = 1 + 2\sum_{n=1}^{N}\cos[kx_n\cos(\theta)];\quad M = 2N+1 \tag{2}$$

where $k = 2\pi/\lambda$ is the wave number, λ represents wavelength, θ is the azimuth angle and x_n is the position of nth element. There is an element at the origin for the odd element array.

3. Cat swarm optimization

3.1. Classical CSO

Cat swarm optimization is modeled by identifying specific characteristic features of a cat's behavior. Thus there are two modes of operation of the CSO: the seeking mode and the tracing mode. The cats are distributed to the two modes based on mixture ratio (MR).

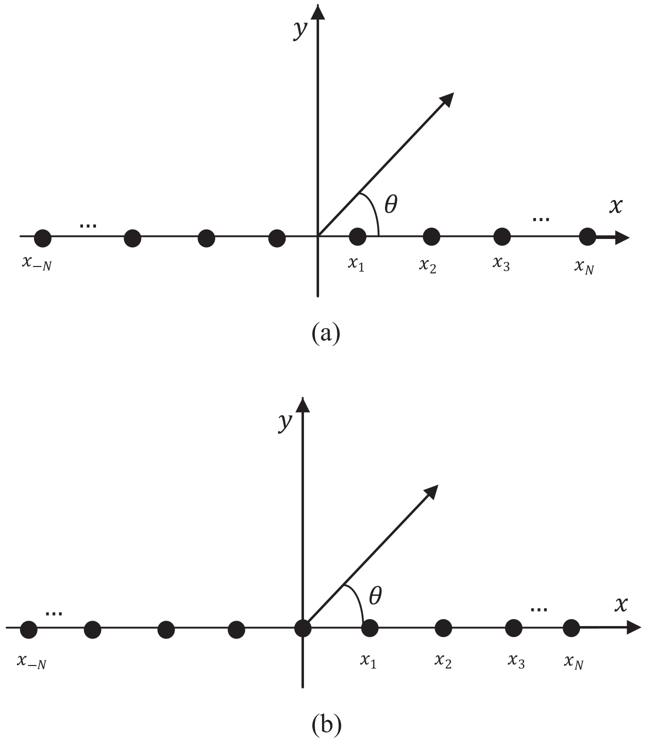

Fig. 2. Geometry of M-element linear array (a) even and (b) odd.