DOA Estimation Using Subarray Dividing and Interpolated ESPRIT Algorithm for Multi-circle Conical Conformal Array

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1. Introduction

Conformal antenna array, i.e., an array that conforms to an arbitrary surface, the application of that is much wider on future communication and defense [1].By contrast with ordinary arrays, adaptive conformal antenna array has some remarkable advantages, for instance, does not affect the aerodynamic characteristics of aerocraft, expanding the scanning range, increasing the effective aperture, high gain, overcoming the effects of platform, reducing RCS, and so on. But at the same time, due to the special conformal arrays and complex electromagnetic identities, there are a number of difficulties when the conformal array is used on wide range DOA estimation. Firstly, conformal array has the ‘‘shadow effect’’ because of the metallic carrier, which means for an incident wave from a special angle, some of the antenna elements can not receive the signal. Secondly, the radiation pattern of antenna element cannot be regarded as omni-directional since the platform behaves as a metallic ground. Therefore, for a conformal array, the elements’ radiation patterns are always directional. Thirdly, the classical spectrum estimation cannot be used to the whole array, when several elements do not work.

Most high resolution DOA estimation algorithms, such as MUSIC-based [2] and ESPRIT-based [3] algorithms, require the array’s steering vector is complete (i.e. all the elements can receive the signal) and the radiation pattern of antenna elements are omni-directional. These algorithms cannot use to conformal array directly because of the array cannot satisfy above assumptions. Subarray dividing technique given by [4] can solve above problems efficiently, while complexity of the spectral searching in which is too high to fit for real-time applications. ESPRIT algorithm is a search-free DOA estimation algorithm, which exhibits lower computation and storage requirements than MUSIC algorithm by using a displacement invariant array. Though phase mode based ESPRIT algorithm can be applied to uniform circular array while classical ESPRIT algorithm can only be applied to uniform linear array, it cannot be used to conformal array, because of that the periodic excitation condition will be destroyed due to the incomplete steering vector [5].

In this paper, subarray dividing and interpolated ESPRIT-based methods are combined together for

DOA estimation on conical conformal array. Simulation results exhibit the efficiency and accuracy of this method.

2. Interpolated ESPRIT based on subarray dividing technique

Figure 1 represents a conical conformal array of a cone angle of 2α, and $2M$ microstrip antennas are uniformly distributed over the circumference of radii r ($r = \lambda / \left(4\sin\left(\pi / M\right)\right)$ and $r = \lambda / \left(4.34\sin\left(\pi / M\right)\right)$). Fig.2 shows the radiation pattern of E_ϕ of one of the elements simulated by HFSS. Let L $(L < M)$ narrowband plane waves, impinge on the array from azimuth $\phi_i \left(i = 1, 2, \ldots, L\right)$.The $M \times 1$ received signal vector of the array is given by

$$\mathbf{X}(t) = \mathbf{F} \bullet \mathbf{K} \bullet \mathbf{A}\mathbf{S}(t) + \mathbf{N}(t) \tag{1}$$

where $\mathbf{S}(t)$ is an $L \times 1$ vector whose i th element associated with the i th signal. $\mathbf{A}$ is an $M \times L$ steering matrix. $\mathbf{N}(t)$ represents additive white Gaussian noise. $\mathbf{F}$ is an $M \times L$ radiation pattern matrix, which denotes i th $\left(i = 1, 2, \ldots, M\right)$ antenna's response to l th $\left(l = 1, 2, \ldots, L\right)$ signal. $\mathbf{K}$ is a polarization matrix.

Assume that a signal comes from $\pi / 2$ impinging on the array, in this case, only half of the whole array can receive this signal, and the signal's steering vector can be expressed as

$$\boldsymbol{a}(\pi / 2) = [e^{jkr\cos(\frac{\pi}{2} - \frac{\pi}{16})}, e^{jkr\cos(\frac{\pi}{2} - \frac{3\pi}{16})}, \ldots, e^{jkr\cos(\frac{\pi}{2} - \frac{15\pi}{16})}, 0, \ldots, 0]^T \tag{2}$$

It can be seen that the steering vector is incomplete for the conformal array, furthermore, each antenna element has a different response to a certain signal. To solve this problem, we divide the whole array into 8 subarrays, each of that spans a sector of $\pi / 2$ .Each subarray has 4 antenna elements. Through this way, for any signal, we can always find a subarray, all of whose elements can receive the signal, which means its steering vector is "complete".

The principle of interpolated array is dividing the field of view of the array into n sectors, the size of which depends on the array geometry and the desired interpolation accuracy [6]. Assuming that a signal, whose DOA is in the sector $\Phi \in [\phi_1, \phi_2]$ .Let $\Delta\phi$ as the interpolation step, then Φ can be represented as

$$\Phi = [\phi_1, \phi_1 + \Delta\phi, \phi_1 + 2\Delta\phi, \ldots, \phi_2 - \Delta\phi, \phi_2] \tag{3}$$

The real array manifold is

$$\mathbf{A} = [\mathbf{a}(\phi_1), \mathbf{a}(\phi_1 + \Delta\phi), \mathbf{a}(\phi_1 + 2\Delta\phi), \ldots, \mathbf{a}(\phi_2)] \tag{4}$$

In the same sector Φ, the virtual array steering matrix is

$$\tilde{\mathbf{A}} = [\tilde{\mathbf{a}}(\phi_1), \tilde{\mathbf{a}}(\phi_1 + \Delta\phi), \tilde{\mathbf{a}}(\phi_1 + 2\Delta\phi), \ldots, \tilde{\mathbf{a}}(\phi_2)] \tag{5}$$

Then an interpolation matrix $\mathbf{B}$ is designed to satisfy

$$\mathbf{B}^{\mathbf{H}}[\mathbf{F} \bullet \mathbf{K} \bullet \mathbf{A}(\phi)] = \tilde{\mathbf{A}}(\phi), \phi \in \Phi \tag{6}$$

To find the accurate matrix $\mathbf{B}$, we can compute the ratio of the Frobenius norms

$$\left\| \tilde{\mathbf{A}} - \mathbf{B}^{\mathbf{H}} (\mathbf{F} \bullet \mathbf{K} \bullet \mathbf{A}) \right\| / \left\| \tilde{\mathbf{A}} \right\| \tag{7}$$

If the ratio is small enough, for example, 0.001, then we accept $\mathbf{B}$, otherwise, we can reduce $\Delta\phi$ or change the form of the interpolation array and recalculate it. Though the interpolation procedure is time consuming, it can be done off-line. We can compute $\mathbf{B}$ once for any given array and store them in the system.

ESPRIT is an efficient algorithm for DOA estimation, whose computation is lower than MUSIC due to its search-free character. Through the interpolation methods, we can use ESPRIT to estimate DOA via the virtual linear array. LS (least square) and TLS (total least square)-ESPRIT are two typical algorithms of the ESPRIT-based algorithms [3][7][8].

3. Simulation results

In this section, we evaluate the performance of the estimation methods described above, using Monte Carlo simulations. The simulations use the model shown in Fig.1, 16 microstrip antennas are mounted on the surface of the metallic cone with radii of the circular array are $r = \lambda / \left(4\sin\left(\pi/16\right)\right)$ and $r = \lambda / \left(4.43\sin\left(\pi/16\right)\right)$, cone angle of which is 16.4°. The antenna elements are U-shaped slot patches [9]. Assuming that there are two uncorrelated narrowband signals which impinge on the array with the DOA of $\phi = \pi/4$ and $\phi = \pi/2$. The snapshots (sample points of the array) are 512.The interpolation sector for each subarray is set to $2\pi/9$, and the interpolation step is 0.1°. We compute the estimated error versus SNR on the two circular arrays respectively, and then combine them to obtain the final RMS error versus SNR. 100 independent measurements are carried out. Fig.3 shows subarray dividing LS and TLS-ESPRIT algorithms' performance.

4. Conclusion

A modified method for DOA estimation on a conical conformal array is proposed. Through subarray dividing and interpolation technique, ESPRIT-based algorithm can be applied not only in conical but also in any other curve conformal geometries. Simulation results demonstrate the efficiency and accuracy of the proposed method.

Acknowledgment

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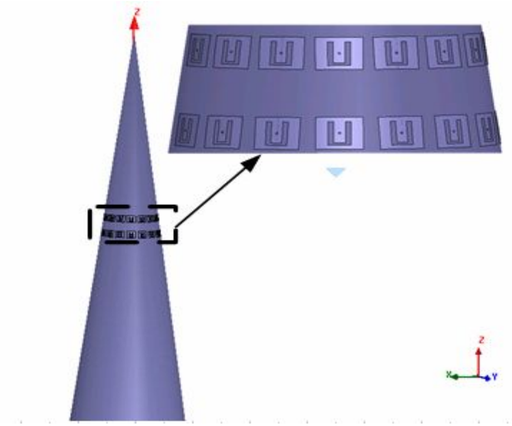


Figure 1: Conical conformal array

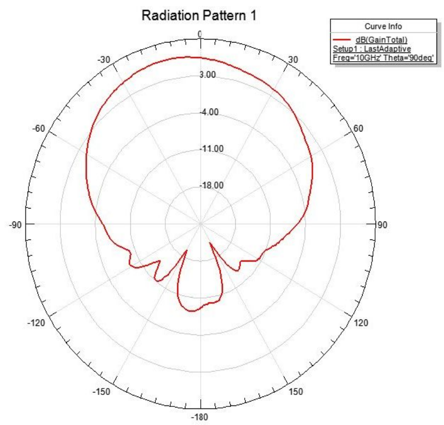
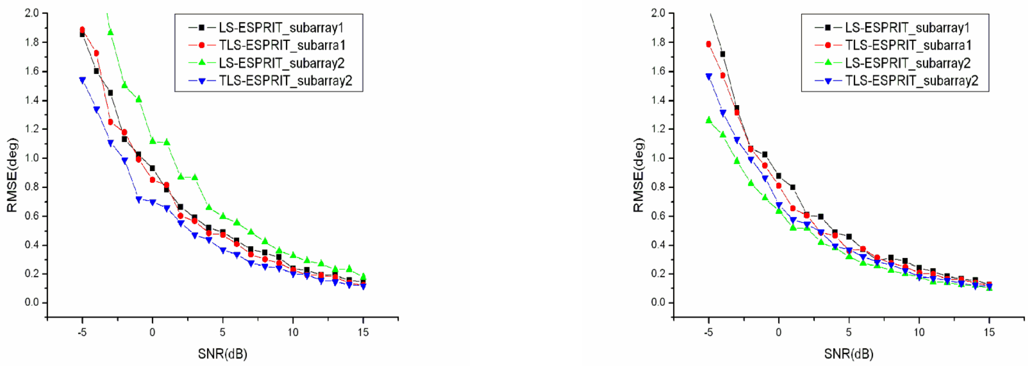


Figure 2: Radiation pattern of one element



(a) $\phi = 45^{\circ}$

(b) $\phi = 90^{\circ}$

Figure 3: The estimated RMS error versus SNR on two subarrays when $\phi = 45^{\circ}$ and $\phi = 90^{\circ}$