Performance Analysis of Radially Polarized Conformal Array in DOA and Polarization Estimation

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***Abstract*—This paper presents the performance study of the radially polarized conformal array in DOA and polarization estimation of multiple sources. The radially polarized circular array can consist of conformal antenna elements like microstrip patch antenna. The DOA and polarization estimation method based on 2-element uniform linear array is reviewed and error analysis is carried out to validate the performance. Simulation results show that the array can estimate 2-D DOA with linear polarization from high grazing angles with good estimation accuracy. Moreover, it also has acceptable performance even when element failure occurs.**

Keywords—DOA estimation; polarization estimation; circular array; conformal array

I. INTRODUCTION

Recently, conformal array is attracting great attention especially in areas like navigation, military, surveillance and airborne radar, owing to its advantages in low profile and adaptability to different mounting structures. DOA and polarization parameter estimation using antenna array has been researched for decades due to its importance in both civil and military sectors. Various estimation methods have been studied with variety of array elements, such as linear collocated dipole antenna array using ESPRIT method by exploiting the invariance property of the array structure for angle and polarization estimation [1], arbitrary distributed array elements based on calibration measurements and polarimetric element-space (PES) algorithm for joint DOA and polarization estimation [2]. Methods using conformal antenna array for DOA estimation have also been researched with increasing interest. In [3], a 2D DFT-ESPRIT method was studied based on a 2D cylindrical antenna array with conformal elements. Conical array with conformal elements was also studied. The author in [4] investigated DOA estimation using conformal microstrip patch array antenna and derived the CRLB for the estimation. However, the polarization estimation was not considered in the study.

All of the aforementioned estimation methods consider the array as a whole unit. However, when array elements fail, the estimation accuracy will greatly degrade. It is noted that the approach previously proposed in [5] has the potential to maintain performance once element failure occur. In this paper, the method in [5] based on 2-element ULA was reviewed and applied on estimating DOA and polarization parameters of multiple sources using planar circular conformal array. Performance of the array with and without element failure are also studied. One thing to note is that the estimation approach in [5] didn't specify the element type of the array. In this paper, microstrip patch antenna is assumed for the array. Yet for simplicity, the radiation patterns of all the antenna elements in the upper half-sphere are assumed the same. Mutual coupling between antenna elements are not considered.

II. RADIALLY POLARIZED CONFORMAL ARRAY

A. Conformal Circular Array

It is evident that by using microstrip patch antenna as array elements, the circular array become conformal and the element polarization can be arranged easily according to the polarization direction of the patch antenna. When the polarization direction of the patch antenna is arranged along the radial direction of a circle, it is named radially polarized (illustrated in Fig. 1).

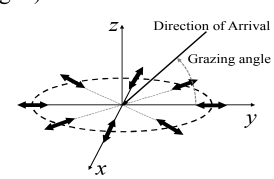

Fig. 1. Illustration of radially polarized circular array.

Assume that there are N elements in the radially polarized conformal circular array (RPCCA), N is even number. Similar as that in [5], two elements in opposite sides can form a 2-element ULA. By ignoring the mutual coupling effects, N/2 number of ULA can be formed.

B. DOA and Polarization Estimation

The DOA and polarization angle estimation approach is reviewed in this section. Assume that there are Q independent, uncorrelated narrowband signal sources present in the far field with different frequencies. Filtering can be used to separate source signals before parameter estimation. The signal parameters of the qth source are denoted as $(\theta_q,\phi_q,\gamma_q)$, θ and ϕ are the 2-D DOA angles, γ is the polarization angle (only linearly polarization is considered). Let the number of 2-element ULA be M (M=N/2), then for the mth ULA, the 1-D DOA angle Φ of each source with respect to its array axis can be estimated by applying the MUSIC approach,

$$P_m(\Phi) = 1 \Big/ \left[\boldsymbol{e}_m^H(\Phi) \mathbf{B_n} \mathbf{B_n}^H \boldsymbol{e}_m(\Phi) \right] \quad (1)$$

where $\mathbf{B}_n$ is the noise subspace decomposed from the *m*th ULA output signal covariance matrix and $\Phi \epsilon [0°,180°]$, $\boldsymbol{e}_m$ is the steering vector of the *m*th ULA. The inter-element spacing of the ULA is set to be half-wavelength.

The 2-D DOA of the *q*th source signal is related to the 1-D DOA Φ [5] and can be estimated by (2) to (3),

$$\hat{\theta}_q = \arcsin\left(\sqrt{\cos^2 \hat{\Phi}_u^q + \cos^2 \hat{\Phi}_v^q}\right) \quad (2)$$

$$\hat{\phi}_q = \begin{cases} \phi_u + \arccos(a_1) \ \in [\phi_u, \phi_u + \pi], & \text{if } a_2 \geq 0 \\ \phi_u - \arccos(a_1) \ \in [\phi_u - \pi, \phi_u], & \text{if } a_2 < 0 \end{cases} \quad (3)$$

where a_1 and a_2 can be found in [5], u and v refer to the array axes index of two selected ULAs among the M ULAs for the estimation, ϕ_u is the azimuth angle of the first selected axis with respect to the x-axis. Since there are M ULAs available, there can be C_M^2 sets of u and v. Thus, the final DOA estimation is the average value of all the sets.

Estimation of the polarization angle can be obtained by using the estimated 2-D DOA angles and the final estimation is the average value of all the (u, v) sets.

$$\begin{bmatrix} E_u^q \\ E_v^q \end{bmatrix} = \begin{bmatrix} \cos\theta_q \cos\phi_q & -\sin\phi_q \\ \cos\theta_q \sin\phi_q & \cos\phi_q \end{bmatrix} \begin{bmatrix} E_\theta^q \\ E_\phi^q \end{bmatrix}, \ \gamma_q = \arctan\left(\frac{E_\phi^q}{E_\theta^q}\right) \quad (4)$$

It can be noted that when one element fails, there are still M-1 number of ULAs and the angle estimation can still be obtained by using the C_{M-1}^2 combinations. The estimation result can still maintain acceptable accuracy.

III. Performance Analysis

Performance analysis has been carried out to validate the performance of the approach. Root-mean-square error (RMSE) is used to evaluate the performance, 100 trials are used to estimate each parameter. Single source is assumed in the first scenario. The elevation angle θ is varied and RMS errors at different SNR values are shown in Fig. 2. The results show that the approach can have better estimation accuracy at high grazing angles than low grazing angles. Fig. 3 shows the RMSE comparison between normal case and element failure case. One element is failed in the case. From the results, we can see that the estimation error does not vary much from the normal case except estimation of γ at low SNR value. In the second scenario, multiple sources with different frequencies are considered. RMSE of various number of sources at different SNR values are shown in Fig. 4. It can be seen that the more sources, the lower the estimation accuracy.

IV. Conclusion

This paper presents the performance study of the approach based on RPCCA for DOA and polarization estimation. Simulation results show that the approach can have good estimation accuracy when multiple sources are present. Besides, it also has acceptable performance when element failure occurs.

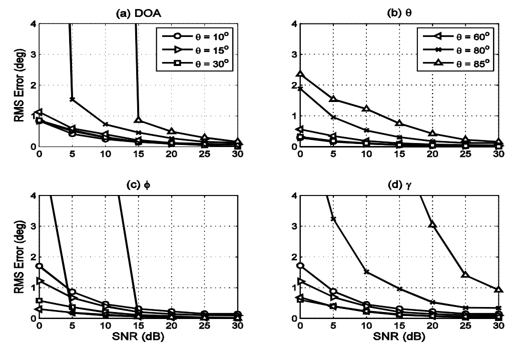

Fig. 2. RMSE of estimation at different SNR values from 0dB to 30dB.

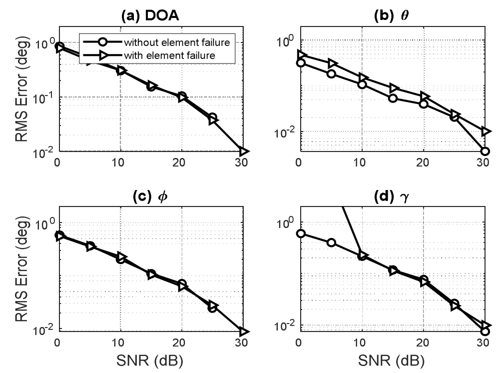

Fig. 3. RMSE comparison between normal case and element failure case.

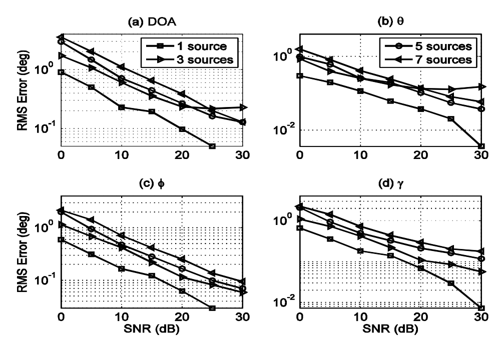

Fig. 4. RMSE when different number of sources are present (0dB to 30dB).

References

[1] J. Li and R. T. Compton, "Angle and polarization estimation using ESPRIT with a polarization sensitive array," in *IEEE Trans. Antennas and Propag*., vol. 39, pp. 1376-1383, Sep. 1991..

[2] M. Costa, A. Richter and V. Koivunen, "DoA and polarization estimation for arbitrary array configurations," in *IEEE Trans. Signal Process*., vol. 60, pp. 2330-2343, May 2012.

[3] P. Yang, et. al., "Fast 2-D DOA and polarization estimation using arbitrary conformal antenna array," *Progress In Electromagnetics Research C*, vol. 25, pp. 119-132, 2012.

[4] S. Mohammadi, A. Ghani and S. H. Sedighy, "Direction-of-Arrival estimation in conformal microstrip patch array antenna," in *IEEE Trans. Antennas Propag*., vol. 66, pp. 511-515, Jan. 2018.

[5] L. Huang and Y.L. Lu, "Multiple sources DOA and polarization estimation using vector circular array," *Proc. 2013 IET International Radar Conference*, Xian, China, 14-16 Apr 2013.