Highly Accurate Direction-of-Arrival Estimation with a Uniform Circular Array

Kuan-Hao Chen and Jean-Fu Kiang
Graduate Institute of Communication Engineering, National Taiwan University, Taipei, Taiwan 106, ROC

Abstract - **A mutual coupling compensation method is proposed to enhance the estimation accuracy of an incident wave upon a uniform circular array (UCA), with the initial guess estimated using the UCA-rank reduction (RARE) method. Simulation results under various signal-to-noise ratios confirm the effectiveness of the proposed method.**

Index Terms — **Direction of arrival, coupling compensation, circular array.**

I. INTRODUCTION

Uniform circular arrays (UCA's) have been used to estimate the directions of arrival (DOA's) of signals, including both the azimuthal and zenith angles. Several algorithms have been proposed to estimate DOA's using UCA's, including UCA-RB-MUSIC, UCA-ESPRIT [1] and UCA-RARE [2]. However, their performance is often degraded by mutual coupling among antenna elements in the array.

In [3], a coupling matrix has been introduced to compensate for the mutual coupling. In [4], a search-free 2D DOA estimation algorithm, based on UCA-RARE [2] and root-MUSIC, was proposed for UCA's, in which the mutual coupling is taken into account.

A 2D DOA estimation algorithm, taking into account the elevation-dependent mutual coupling, was proposed for small UCA's [5], in which the azimuth estimation is decoupled from the elevation estimation.

In this work, a rigorous mutual coupling compensation method is proposed to compensate the mutual coupling embedded in the received voltages from a uniform circular array (UCA). The 2D DOA estimation method in [5] is applied to obtain the initial guess. The proposed method is then applied to accurately estimate the incident angle in both the azimuthal and the zenith directions.

II. COUPLING COMPENSATION BASED ON RECIPROCITY THEOREM

Fig.1 shows a uniform circular array (UCA), with N_d identical dipoles uniformly distributed over a circle of radius R. All the dipoles are aligned in the z direction, with their phase centers lying in the xy-plane.

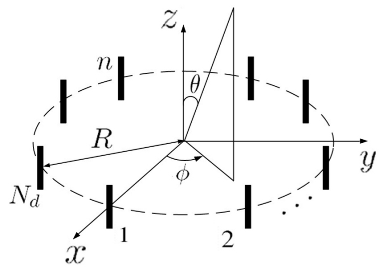

Fig. 1. Uniform circular array composed of N_d dipoles.

When there are plane waves impinging upon the UCA, the received signals of this array can be expressed in terms of steering vectors associated with these incident signals. The received signals are then transformed into the beam space as in [6]. The beam-space MUSIC algorithm is then applied to estimate the signal DOA's from the deepest nulls of a cost function. The coupling among dipoles of the array will compromise the estimated DOA's.

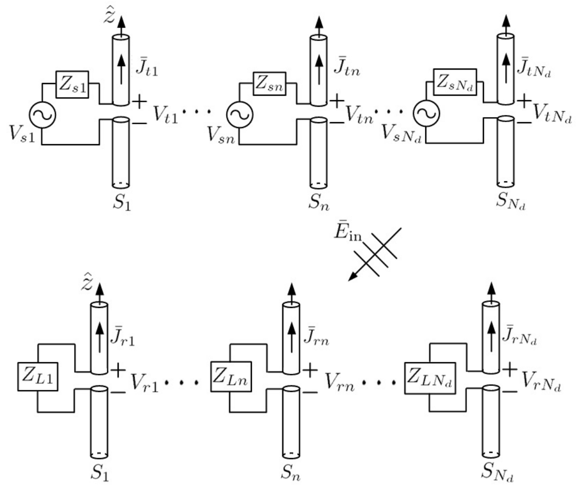

Fig. 2. An array of N_d dipoles in (a) transmitting mode and (b) receiving mode.

The received voltage on each dipole can be related to the incident field via a coupling matrix [7]. Fig.2 shows an array of N_d dipoles in the transmitting mode and the receiving mode, respectively. By applying the reciprocity theorem, the uncoupled open-circuit voltages can be derived from the received voltages in terms of the coupling matrix as well as a coupling voltage vector which is a function of the incident angle. By incorporating the angle-dependent information into the coupling compensation scheme, the incident angle can be estimated to a higher degree of accuracy.

III. RESULTS AND DISCUSSIONS

Fig.3 shows the effect of SNR on the root-mean-square error (RMSE) of the estimated azimuthal angle. The RMSE of the estimated azimuthal angle falls in the range of 0.02^{o}~ 0.1^{o} by using the UCA-RARE algorithm; and is almost 0^{o} by using the proposed method.

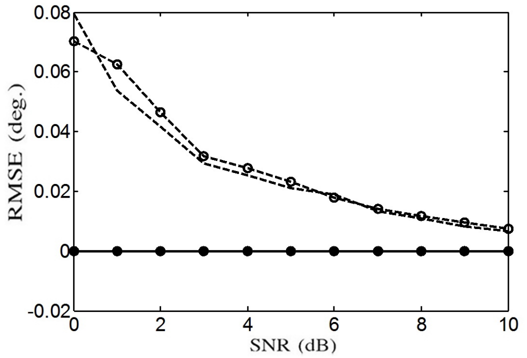

Fig. 1. Effect of SNR on RMSE of azimuthal angle over 100 Monte-Carlo realizations. ——: proposed method ($\theta_i = 80^o$, $\phi_i = 30^o$); ------: UCA-RARE ($\theta_i = 80^o$, $\phi_i = 30^o$); --●-$: proposed method ($\theta_i = 47^o$, $\phi_i = 30^o$); --o-- UCA-RARE ($\theta_i = 47^o$, $\phi_i = 30^o$).

IV. CONCLUSION

A rigorous coupling compensation method is proposed to acquire a highly accurate DOA estimation with a uniform circular array. The root-mean-square error based on Monte-Carlo simulations is almost zero in both the azimuthal and the zenith angles, much better than the results using the algorithms in the literatures.

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