A method of single-direction calibration for accurate DoA estimation

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Abstract—**This paper proposes an efficient calibration method of array manifolds for accurate direction of arrival (DOA) estimation. The DOA is estimated by using the conventional multiple source classification (MUSIC) algorithm, and the accuracy of the proposed method is compared to that of the conventional calibration method to verify the suitability. The proposed method calibrates the entire array manifold using a true steering vector obtained from a single direction and maintains an average estimation error of 2.9°. The results demonstrate that accurate DOA estimation can be achieved by the proposed method with reduced calibration complexity.**

Keywords—array manifold calibration, direction finding, direction of arrival estimation.

I. INTRODUCTION

Direction finding (DF) systems are widely employed on military aeronautic weapons to estimate the direction of radio sources using antenna arrays. These arrays are used to determine the source direction by comparing the pre-saved array manifold with the real-time measurement; however, the real-time data are easily distorted by the mutual coupling effect, which also lowers the DF accuracy [1]−[3]. Thus, there have been a lot of effort made to calibrate the array manifold for accurate direction of arrival (DOA) estimation [4], [5]. Although the accurate calibration can be achieved by measuring steering vectors for all source directions, it requires tremendous time, cost, and man power, especially when the array antennas are mounted on huge platforms [6].

In this paper, we present an efficient calibration method of array manifolds for accurate DOA estimation. The DOA is estimated by using the conventional multiple source classification (MUSIC) algorithm [7], and the accuracy of the proposed method is compared to that of the conventional calibration method to verify the suitability. The results prove that the proposed method is more efficient when the number of measured steering vectors is limited to a few measurements.

II. PROPOSED CALIBRATION METHOD

Fig. 1 shows a commercial off-the-shelf antenna from Amotech that is used as individual elements of a 7-element array [8]. Detailed design parameters are listed in Table 1, and the geometry is modeled as piece-wise mesh triangles in FEKO EM simulator [9]. The simulated reflection coefficient is −12.6 dB at 1.575 GHz, and is similar to the measured value of −18.6 dB. The bore-sight gain also shows a good agreement, for example, the measured gain at 1.575 GHz is 0.9 dBic, which is similar to the simulated value of 0.6 dBic.

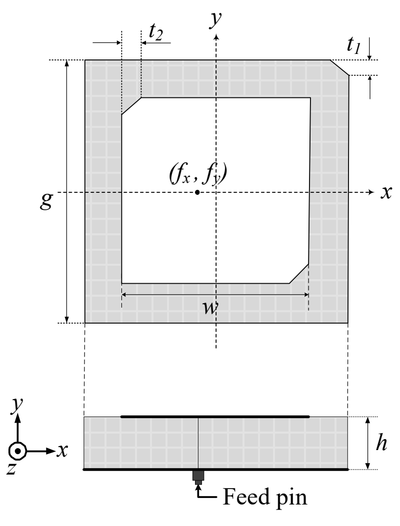

Fig. 1. A commercial off-the-shelf microstrip patch antenna from Amotech.

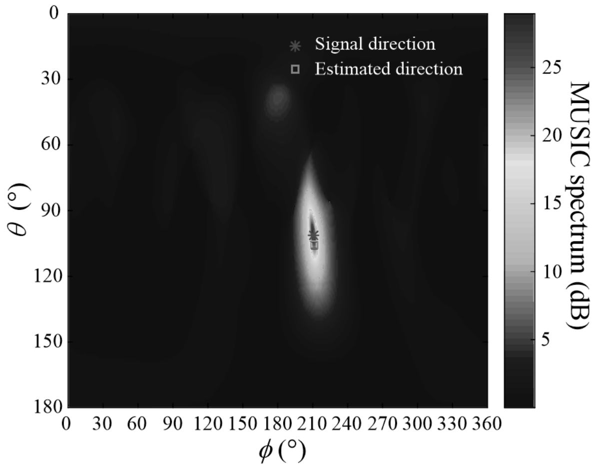

Fig. 2. An example array pattern of the proposed calibration method.

TABLE I. DESIGN PARAMETERS OF THE ANTENNA

Parameter	w	g	t_1	t_2	(f_x, f_y)	h
Value	12.8	18	1.1	1.3	(−1.1, 0)	4

a. Unit: mm

Seven identical elements are arranged on a circular ground platform with a diameter of 262 mm, and the array radius is set to be 106 mm, so that the inter element spacing is maintained to be about a half wavelength. The array manifold of the array is obtained from port currents induced by plane wave sources, whose incident angles are adjusted to compute true steering vectors from different angles. Then, the theoretical array manifold is calibrated by using 684 true steering vectors, and the conventional calibration matrix is calculated by (1).

$$\bar{C} = \left(\bar{A}_{True} \cdot \bar{A}^{H}_{Theory}\right) \cdot \left(\bar{A}_{Theory} \cdot \bar{A}^{H}_{Theory}\right)^{-1} \quad (1)$$

The proposed method calibrates the theoretical array manifold using a calibration vector that is computed by using a single steering vector at one direction as in (2).

$$\bar{V} = \bar{a}_{True} \circ \bar{a}^{*}_{Tehory} \quad (2)$$

Fig. 2 presents an example array pattern of the proposed calibration method. It is assumed that the pattern is calculated by the MUSIC algorithm, and the incident angle of the signal is $\phi = 210°$ and $\theta = 105°$. The root mean square (RMS) error is 2.9°, which is similar to the conventional method of 2.1°. However, the RMS error of the conventional method is highly dependent on the number of true steering vectors, for example, the error is greater than 10° when the number is decreased to less than 12. Thus, we can verify that better accuracy can be obtained by the proposed method when the number of true steering vectors is limited.

III. CONCLUSION

This paper investigated the efficient calibration method of array manifolds for accurate DOA estimation. The DOA was estimated by using the MUSIC algorithm, and the accuracy of the proposed method was compared to that of the conventional calibration method to verify the suitability. The proposed method maintains an average estimation error of 2.9°; however, the RMS error of the conventional method is increased to about 10° when the number of true steering vectors is insufficient. Thus, we can verify that the proposed method is suitable to achieve accurate DOA estimation with reduced calibration complexity compared to the conventional approach.

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