Array Configuration Optimization using an Objective Function for Accurate DOA Estimation

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Abstract — **This paper proposes a deterministic method of array configurations using an objective function for accurate DOA estimation in a wide frequency range. The objective function is defined to describe appropriate baseline distributions of an 8-elemnt circular array for the max-min frequency ratio of 6:1 and used to finds the most similar distributions among a number of random array configurations. The resulting array configuration obtained from the proposed method is evaluated by root mean square error (RMSE) and ambiguity in comparison with a uniform circular array (UCA). The results demonstrate that the proposed method is efficient for achieving accurate DOA estimation in a wide frequency range.**

Index Terms **— Direction finding, DOA estimation.**

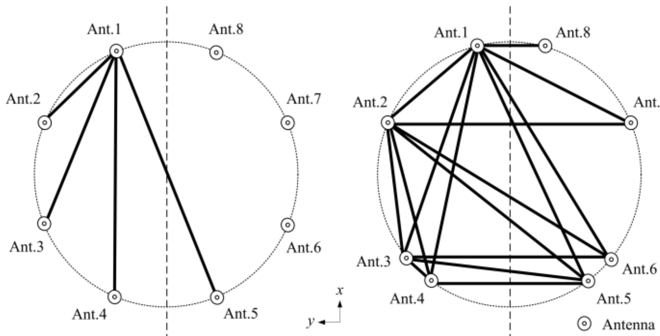
I. INTRODUCTION

Direction finding (DF) systems are widely adopted in many applications, such as radio navigation, transmitter identification, and mobile device tracking. These DF systems usually use antenna arrays to estimate radio source directions by comparing amplitude differences and phase delays of the received array signals [1]. Therefore, the baseline, which is a term indicating a line that is chosen for amplitude and phase comparisons, should be carefully determined for accurate direction of arrival (DOA) estimation [2]. In this paper, we propose a deterministic method of array configurations using an objective function of baselines for accurate DOA estimation in a wide frequency range. The objective function is defined to find appropriate baseline distributions for an 8-elemnt circular array with a radius of 3 m. The proposed method generates a number of random array configurations, and then finds the most similar baseline distributions out of those random configurations. To verify the suitability of the proposed method, root mean square error (RMSE) and ambiguity of the resulting array configuration are compared with a uniform circular array (UCA) having the same radius. The results demonstrate that our method is suitable to find the appropriate array configuration for accurate DOA estimation in a wide frequency range.

II. PROPOSED BASELINE OPTIMIZATION METHOD

Fig. 1 shows a comparison of baselines between a UCA and a non-UCA, each of which consists of eight elements. Although both array configurations can have up to 28 baselines, the UCA possesses only four different baseline lengths as specified in Fig. 1(a). On the other hand, the non-UCA can have up to sixteen different baseline lengths, when the antennas are placed symmetrically with respect to the *x*-axis. Thus, the non-uniform element spacing can be a better candidate especially for wide-frequency DOA estimation.

Fig. 2 shows the geometry of 8-element circular array in free space. Antennas are assumed to be ideal isotropic point sensors, and their positions are symmetrically determined with respect to the *x*-axis by the parameters of φ_{ant1}, φ_{ant2},…, φ_{ant8} (R_{array} = 3m).



(a) UCA (b) Non-UCA

Fig. 1. Comparison of baseline lengths between the UCA and non-UCA.

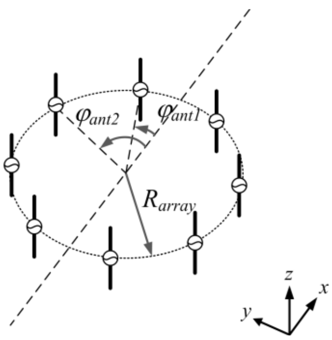


Fig. 2. Geometry of 8-element circular array.

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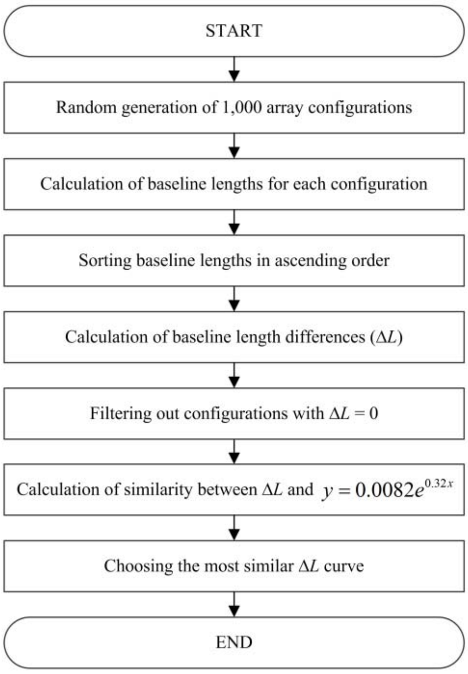

Fig. 3. Flow chart of the proposed optimization method.

Fig. 3 shows a flow chart of the proposed method to determine the array configuration. First, we generate 1,000 random array configurations. Second, we compute sixteen baseline lengths as specified in Fig. 1(b) and sort them in ascending order. Next, we calculate the difference between baseline lengths (ΔL) and then compute similarity between ΔL curves and an objective function curve

$$y = 0.0082e^{0.32n} \quad (1)$$

, where y is the incremental value of ΔL for n-th baseline. The coefficient and the slope of the function are determined by considering the array radius and the operating frequency range. Fig. 4 shows the most similar ΔL curve out of 1,000 random array configurations.

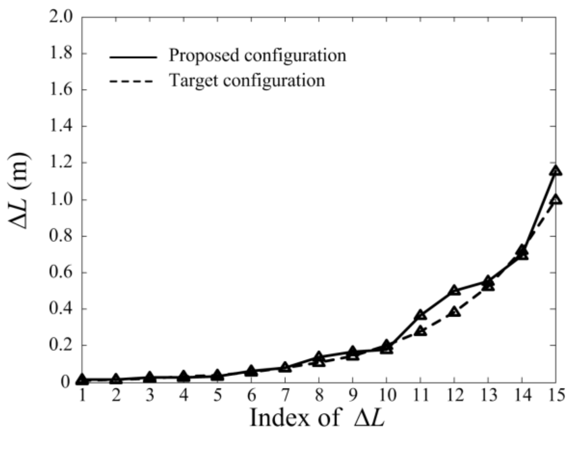

Fig. 4. Proposed ΔL distributions in comparison with the target function.

III. Performance Evaluations

To evaluate the performance of the proposed method, we calculate the RMSE and the ambiguity of the resulting array configuration. It is assumed that the sources are located at every 1° in the azimuth direction, and the signal-to-noise ratio (SNR) is 8 dB. The RMSE is computed by using the difference between the actual source direction and the

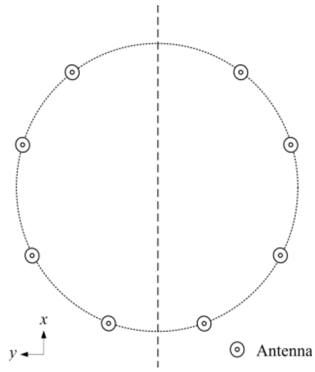

Fig. 5. Proposed array configuration.

TABLE I
ANTENNA POSITIONS

Parameters	UCA	Proposed array
R_{array}	3 m	3 m
φ_{ant1}	0°	35°
φ_{ant2}	45°	73°
φ_{ant3}	90°	117°
φ_{ant4}	135°	160°
φ_{ant5}	180°	200°
φ_{ant6}	225°	243°
φ_{ant7}	270°	287°
φ_{ant8}	315°	325°

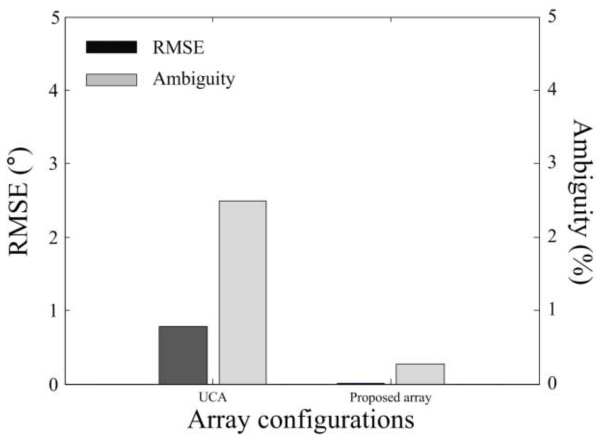

Fig. 6. Performance comparisons between the UCA and the proposed array.

estimated direction that is obtained from the signal-subspace MUSIC algorithm [3], however, in the case that the error is caused by the grating lobes, it is considered as ambiguity.

Fig. 5 shows the geometry of the optimized array configuration corresponding to the Δ*L* curve in Fig. 4, and its antenna positions are shown in Table I. Fig. 6 shows the RMSE and ambiguity values averaged over 100 observations (from 500 MHz to 3 GHz). As can be seen, the overall RMSE of the configuration is improved from 0.78° to 0.01°, and the ambiguity is reduced from 2.5% to 0.3%.

IV. Conclusion

We have investigated the deterministic method of array configurations using the objective function for accurate DOA estimation in the wide frequency range. The objective function was determined for the max-min frequency ratio of 6:1 and the 8-elemnt circular array with the radius of 3 m. The proposed method compared random array configurations with the objective function and determined the appropriate configuration from the most similar baseline distributions. To verify the suitability of the proposed method, RMSE and ambiguity of the resulting array configuration were compared with those of the UCA with the same radius. The method was capable of improving the RMSE by 0.77° and the ambiguity by 2.2%. From the results, we could demonstrate that our method was efficient to achieve accurate DOA estimation in the wide frequency range.

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