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A comprehensive error calibration method based on dual uniform circular array

Key words: Dual uniform circular array; Gain-phase errors; Position errors; Mutual coupling errors; Calibration

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Motivation

- The dual uniform circular array has many advantages similar to those of the uniform circular array (UCA). For example, 360° observations can be achieved, and beams with different directions do not generate gain loss. In addition, the dual uniform circular array can overcome the high sidelobe level of the UCA, which is conducive to the improvement of system capacity.
- In actual applications, the existence of errors will directly result in reduction of performance or even failure of high resolution algorithms (Friedlander and Weiss, 1991; Cheng et al., 2017).

Friedlander B, Weiss AJ, 1991. Direction finding in the presence of mutual coupling. *IEEE Trans Antenn Propag*, 39(3):273-284. https://doi.org/10.1109/8.76322

Cheng F, Gong ZP, Zhang C, et al., 2017. A new rotation measurement-based method for array gain-phase errors calibration. *J Electron Inform Technol*, 39(8):1899-1905 (in Chinese). https://doi.org/10.11999/JEIT161058

Main idea

1. Only one auxiliary source is required to generate three time-disjoint calibration sources with the help of the rotation platform.

2. According to the principle that the signal subspace is orthogonal to the noise subspace, the cost function is constructed. The alternating iteration method is used to estimate the coefficients of the three kinds of errors.

3. The MUSIC algorithm is used to estimate the DOAs of the signals.

Method

1. Combined with the subspace orthogonal principle and cyclic iteration method, the mutual coupling error, position error, and amplitude phase error are calculated.

   (1) Three independent time-disjoint signal sources are obtained with the help of the rotation platform.

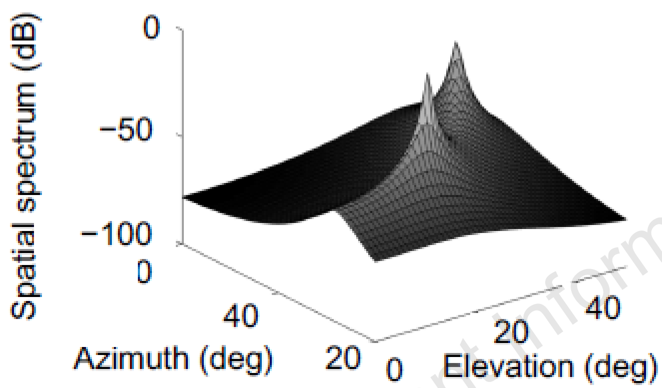
   (2) Combined with the subspace orthogonal principle, an alternating iteration method is used to obtain the error coefficients. During the iterative process to obtain the error coefficients, the algorithm makes full use of the Toeplitz characteristics of partitioned mutual coupling matrices. Furthermore, the signal phase matrix is used to eliminate the phase effect caused by the delay in signal arrival at the antenna array.

2. Combined with the calculated error parameters, the MUSIC algorithm is used to estimate the DOAs of the signals.

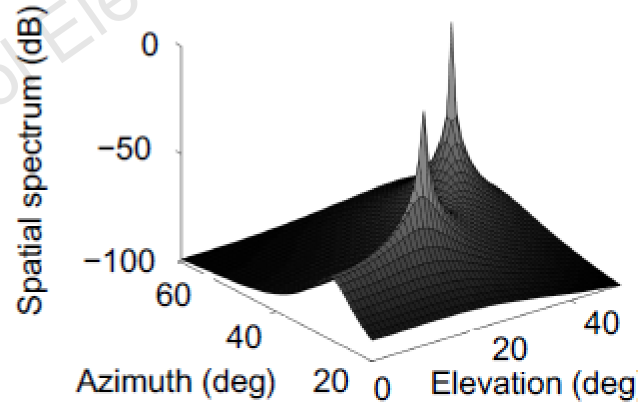
3. Various experiments have been carried out based on the proposed algorithm.

Major results

Compared with Ng and See (1996)'s method, the signal directions estimated by our method are more accurate.



Algorithm in Ng and See (1996)



CECDC algorithm

Ng BC, See CMS, 1996. Sensor array calibration using a maximum-likelihood approach. *IEEE Trans Antenn Propag*, 44(6):827-835. https://doi.org/10.1109/8.509886

Major results (Cont’d)

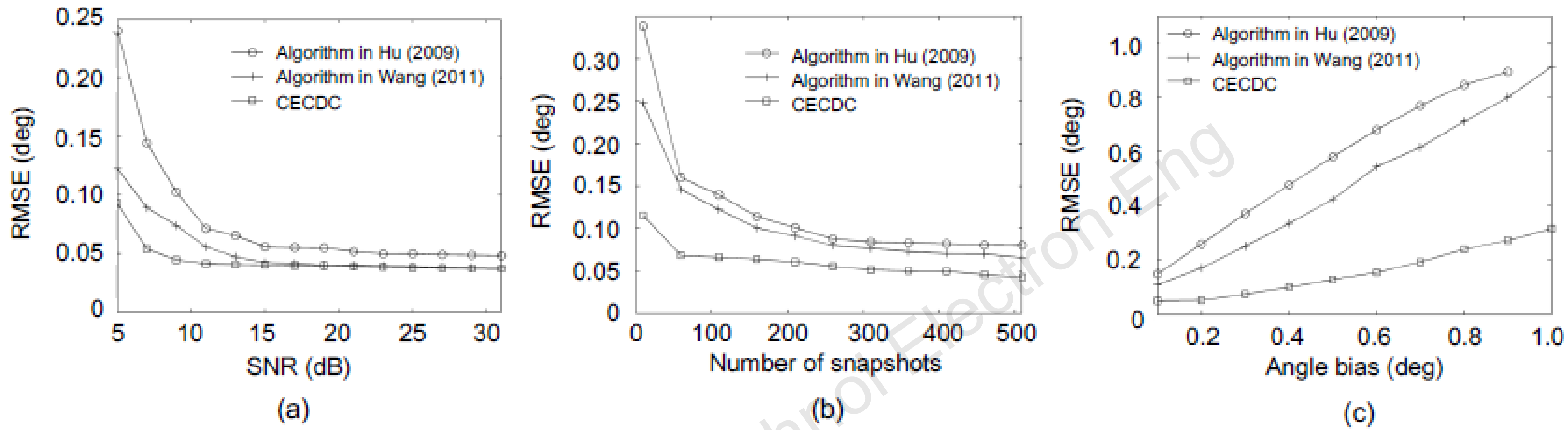


Fig. 7 The effect of calibration sources on estimation performance: (a) RMSE vs. SNR; (b) RMSE vs. the number of snapshots; (c) RMSE vs. angle bias

Figs. 7a and 7b show that the RMSE of the three algorithms gradually decreases with the increase of SNR or the number of snapshots. CECDC has better estimation accuracy than the algorithms in Hu (2009) and Wang (2011). Fig. 7c shows that when the auxiliary source is biased, the performance of CECDC is slightly affected, while the performances of the algorithms in Hu (2009) and Wang (2011) are seriously degraded. When the angle bias exceeds 0.9° , the algorithm in Hu (2009) fails completely.

Hu XQ, 2009. Basis Study on the Application of Super-Resolution Spatial Spectrum Estimation Technique. PhD Thesis, National University of Defense Technology, Changsha, China (in Chinese).

Wang D, 2011. Research on the Errors Calibration Techniques in the Array Signal Processing. PhD Thesis, PLA Information Engineering University, Zhengzhou, China (in Chinese).

Major results (Cont'd)

Table 1 Estimation results of the gain-phase error coefficients

Array element	True value	Estimated value
1	1.0000+0.0000j	1.0000−0.0000j
2	1.5683+0.0688j	1.5683+0.0688j
3	1.7283+0.5418j	1.7279+0.5436j
4	1.2011+0.3710j	1.2007+0.3724j
5	1.5610+0.4357j	1.5613+0.4325j
6	1.1215+0.4905j	1.1211+0.4917j
7	1.1477+0.1371j	1.1476+0.1417j
8	1.1247+0.0342j	1.1246+0.0362j
9	1.3688+0.5268j	1.3693+0.5245j
10	1.2533+0.3077j	1.2524+0.3118j
11	1.1364+0.1370j	1.1369+0.1351j
12	1.2003+0.4088j	1.2000+0.4106j
13	1.4402+0.5240j	1.4413+0.5159j
14	1.3211+0.2103j	1.3198+0.2195j
15	1.0758+0.3947j	1.0747+0.3999j
16	1.2229+0.5507j	1.2247+0.5462j
17	1.5617+0.7905j	1.5600+0.7944j
18	1.1432+0.5861j	1.1443+0.5859j

Table 2 Estimation results of the position error coefficients

Array element	*X* axis		*Y* axis	
	True	Estimated	True	Estimated
1	0.0000	0.0000	0.0000	0.0000
2	−0.1298	−0.1300	−0.1442	−0.1443
3	0.1367	0.1368	0.1397	0.1392
4	0.1250	0.1250	−0.0663	−0.0679
5	−0.1056	−0.1060	0.1180	0.1174
6	−0.1040	−0.1040	−0.0986	−0.0994
7	−0.1549	−0.1549	−0.0573	−0.0578
8	−0.1150	−0.1149	0.1804	0.1800
9	0.1062	0.1063	0.1110	0.1111
10	−0.0630	−0.0629	−0.1316	−0.1323
11	−0.1347	−0.1345	0.1888	0.1877
12	−0.0197	−0.0195	0.0294	0.0295
13	0.0913	0.0911	0.1251	0.1250
14	0.1615	0.1615	0.0522	0.0522
15	−0.1846	−0.1850	−0.1584	−0.1586
16	−0.1539	−0.1539	0.1195	0.1194
17	0.1305	0.1304	0.1081	0.1083
18	−0.1916	−0.1916	−0.1374	−0.1372

Table 3 Estimation results of the mutual coupling coefficients

	True value	Estimated value
$g(2)$	0.7821+0.2583j	0.7822+0.2583j
$g(3)$	−0.5476+0.2469j	−0.5477+0.2469j
$b(1)$	0.6624−0.2503j	0.6624−0.2504j
$b(2)$	−0.5326+0.2369j	−0.5326+0.2369j
$c(2)$	0.4982+0.2315j	0.4982+0.2314j

- Tables 1–3 verify that our algorithm can accurately estimate the three kinds of error coefficients.

Conclusions

- Aimed at the situation where gainphase errors, position errors, and mutual coupling errors coexist in a dual uniform circular array, a new method is proposed to comprehensively deal with the errors and estimate the DOAs of incoherent sources.
- The new algorithm combines subspace orthogonality and loop iteration. During the iterative process in which the error coefficients will be solved, the algorithm makes full use of the Toeplitz characteristics of partitioned mutual coupling matrices. The signal phase matrix is used to eliminate the phase effect caused by the delay in signal arrival at the antenna array.
- Simulation results show that the algorithm can effectively estimate the directions of the signals and solve the problem of comprehensive error calibration for the dual uniform circular array.