DOA Estimation of Direct Wave in Multipath Environments Using FFT-FOCUSS with Adaptive Change of Angle Bin Spacing

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1. Introduction

In the DOA estimation of the first-arrival wave in a multipath environment, the median algorithm with multiple thinned arrays in FFT-FOCUSS was shown to improve the estimation accuracy [1]. This study demonstrates that the scheme of adaptively changing the angle bin spacing further improves the estimation accuracy of the DOA estimation.

2. DOA Estimation Using FFT-FOCUSS

2.1 FOCUSS with FFT: FFT-FOCUSS

We use a K-element uniform linear array (ULA) with the element spacing of half wavelength for the DOA estimation in an L-wave multipath environment. The component corresponding to the desired signal frequency is extracted from the frequency spectrum obtained by the FFT of the received signal at each element [2]. Thus, we have the array vector $\boldsymbol{x}$ from all element components, which is modeled using N angle bins, $\theta_1, \cdots, \theta_N$, as follows:

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{s} + \boldsymbol{n} \quad \in \mathbb{C}^{K\times 1} \tag{1}$$

$$\boldsymbol{A} = [\boldsymbol{a}(\theta_1), \ldots, \boldsymbol{a}(\theta_N)] \quad \in \mathbb{C}^{K\times N} \tag{2}$$

$$\boldsymbol{s} = [s_1, \ldots, s_N]^T \quad \in \mathbb{C}^{N\times 1} \tag{3}$$

where $\boldsymbol{a}(\theta_i)$ is the mode vector of θ_i [2], $\boldsymbol{s}$ is the signal vector corresponding to the N angle bins, and $\boldsymbol{n}$ is the noise vector. FOCUSS [3] finds $\boldsymbol{s}$ by minimizing $\|\boldsymbol{s}\|_p^p$ ($p \in [0,1]$) under the condition $\boldsymbol{x} = \boldsymbol{A}\boldsymbol{s}$, and we obtain the estimated vector $\hat{\boldsymbol{s}}$. This is called FFT-FOCUSS.

2.2 Median Algorithm with Multiple Thinned Linear Arrays

For the median algorithm, we configure multiple thinned linear arrays (TLAs) with one element thinned out from the second to the $(K-1)$th element. We apply the median filtering to the DOAs of the first-arrival wave obtained by using FFT-FOCUSS in each of ULA and TLAs [1].

3. Scheme of Changing Angle Bin Spacing

We propose using a scheme of two-step estimation; we estimate roughly the DOAs in the first step and get more accurate DOAs in the second step. In the first step, the wide-angle bin spacing $\Delta\theta^{(1)}$is used for FOCUSS. In the second step, we apply FOCUSS again with the narrower-angle bin spacing $\Delta\theta^{(2)}$ ($< \Delta\theta^{(1)}$) for the areas that are the DOAs estimated in the first step $\pm$ $\Delta\theta^{(1)}$. We call the scheme an adaptive change of angle bin spacing.

4. Performance Analysis by Simulation

Under the conditions in Table I, we conducted computer simulations by randomly varying the DOAs, power ratios, and phases of three multipath waves. The RMSE for the DOA estimates of the first-arrival wave is used to evaluate the estimation accuracy. Fig. 1 shows the CDF of RMSE for three methods: the median algorithms with each of wide- and narrow-angle bin spacings and the proposed two-step method with the median filtering only in the first step. It is found that the proposed method achieves better performance than the others.

5. Conclusion

The algorithm that changes the angle bin spacings in two-step estimation improves the DOA estimation accuracy.

References

[1] K. Ota, N. Kikuma, et al. Proc. IEICE ICETC 2022, Nov. 2022.
[2] K. Miyamoto, N. Kikuma, et al. Proc. IEEE iWEM 2019, Oct. 2019.
[3] I. F. Gorodnitsky, et al., IEEE Trans. Signal Processing, Vol.45, No.3, pp.600-616, Mar. 1997.

Table 1 Simulation conditions.

Carrier frequency	2.45GHz	Search angular area	−90°~90°
Sampling frequency	1MHz	Wide-angle bin spacing	5°
Number of elements (K)	8	Norm value p of 1st step.	0.8
Number of waves (L)	3	Narrow-angle bin spacing	1°
Baseband frequency (CW)	100kHz	Norm value p of 2nd step	0.1
Power of 1st wave	1.0	Regularization parameter	10^{-3}
Powers of 2nd, 3rd waves	0.0 ~ 0.9	Convergence condition (m: iteration number)	$\frac{\|\hat{s}_m - \hat{s}_{m-1}\|}{\|\hat{s}_m\|} < 10^{-3}$
SNR	10dB		
DOAs	−60°~60°	Number of samples (CDF)	1000
Number of FFT snapshots	1024	Number of trials	250

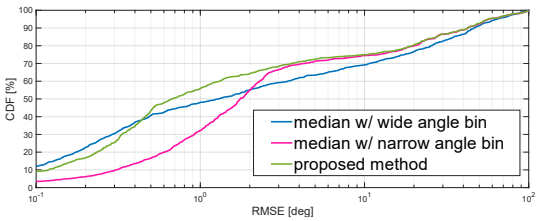

Fig. 1 CDF of RMSE.

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