DOA and Angular Spread Estimation of Clustered Waves by Using Beamspace MUSIC Algorithm

#Hiroki Inoue, Nobuyoshi Kikuma,
Hiroshi Hirayama and Kunio Sakakibara
Department of Computer Science and Engineering, Nagoya Institute of Technology
Gokiso-cho, Showa-ku, Nagoya, 466-8555, Japan, kikuma@m.ieice.org

Abstract

This paper proposes the simple method of estimating both DOA and angular spread of incoming clustered waves by using beamspace MUSIC algorithm. The computer simulation shows the effectiveness of the proposed method.

Keyword: DOA, angular spread, clustered wave, MUSIC algorithm, beamspace, DCMP

1. Introduction

Recently, development of mobile communications is making radio wave environments more complex. To model radio wave environment appropriately and design properly the signal processing algorithms, DOA estimation of incoming waves is required as the effective propagation analysis. Also, each of the incoming waves is sometimes incident in clusters, as is often the case with uplinks of cellular phone systems or MIMO indoor environments, which leads to necessity of estimation of the angular spread as well as DOA of the clustered incoming waves.

The MUSIC algorithm [1] is known as the method of DOA estimation with high angular resolution. Although there are some sophisticated AS estimators [2] [3], we try to estimate simply the AS and DOA by using the MUSIC algorithm with the beamspace technique. In the beamspace, we apply the DCMP (directionally constrained minimization of power) beamformer to create the multiple beampatterns for estimating DOA and AS of each incoming clustered wave.

2. Signal Model and Estimation Algorithm

2.1 Signal Model

Consider that the array antenna used for DOA estimation is a K-element linear array shown in Fig.1, and also that it receives L $(L < K)$ narrow-band waves whose respective DOAs are $\theta_1, \theta_2, \cdots, \theta_L$ and complex amplitudes are $s_1(t), s_2(t), \cdots, s_L(t)$. When the array response vector (mode vector) of the lth incoming wave is given by $\boldsymbol{a}(\theta_l)$ $(l = 1, 2, \cdots, L)$, the array input vector $\boldsymbol{x}(t)$ can be expressed as

$$\boldsymbol{x}(t) = \sum_{l=1}^{L} \boldsymbol{a}(\theta_l) s_l(t) + \boldsymbol{n}(t) = \boldsymbol{A}\boldsymbol{s}(t) + \boldsymbol{n}(t) \tag{1}$$

$$\boldsymbol{A} = [\boldsymbol{a}(\theta_1), \boldsymbol{a}(\theta_2), \cdots, \boldsymbol{a}(\theta_L)], \ \boldsymbol{s}(t) = [s_1(t), s_2(t), \cdots, s_L(t)]^T \tag{2}$$

where $\boldsymbol{A}$ and $\boldsymbol{s}(t)$ are called the array response matrix (mode matrix) and the signal vector, respectively, and $\boldsymbol{n}(t)$ is the internal additive noise vector.

2.2 MUSIC Algorithm

The MUSIC algorithm is the high-resolution method based on the eigenvectors of the covariance matrix of the array input vector. The covariance matrix is given by

$$\boldsymbol{R}_{xx} = E[\boldsymbol{x}(t)\boldsymbol{x}^H(t)] = \boldsymbol{A}\boldsymbol{S}\boldsymbol{A}^H + \sigma^2 \boldsymbol{I} \tag{3}$$

where $\boldsymbol{S} = E[\boldsymbol{s}(t)\boldsymbol{s}(t)^H]$ and σ^2 is the power of internal noise. Then, the MUSIC spectrum is expressed as

$$P_{MU}(\theta) = \frac{\boldsymbol{a}^H(\theta)\boldsymbol{a}(\theta)}{\boldsymbol{a}^H(\theta)\boldsymbol{E}_N\boldsymbol{E}_N^H\boldsymbol{a}(\theta)} \tag{4}$$

$$\boldsymbol{E}_N = [\boldsymbol{e}_{L+1}, \ldots .\boldsymbol{e}_K] \tag{5}$$

where $\boldsymbol{E}_N$ is composed of the eigenvectors: $\{ \boldsymbol{e}_{L+1}, \ldots, \boldsymbol{e}_K \}$ spanning the noise subspace of the covariance matrix $\boldsymbol{R}_{xx}$.

2.3 Estimation of AS

It is assumed that the clustered wave has several elementary waves in the AS. In this paper, we estimate the AS of clustered wave by using the MUSIC algorithm. For example, if we have only one cluster, we can obtain 2 peaks of the MUSIC spectrum by setting the dimension of the signal subspace of the covariance matrix. From the difference of the 2 peaks, AS of the cluster is approximately estimated and the DOA estimate is obtained from the mean value of 2 peak angles. We extend this simple algorithm to the DOA and AS estimation of multiple incoming clusters by employing the beamspace processing iteratively.

3. Adaptive Beamspace Processing

Utilizing the estimated values $\hat{\theta}_l$ ($l = 1, 2, \cdots, L$) in the DCMP criterion of the adaptive antenna, the optimum array weight vector for receiving only the lth wave is computed as follows.

$$\boldsymbol{w}_l(\hat{u}_l) = \frac{\boldsymbol{R}_{zz}^{-1}\boldsymbol{a}(\hat{u}_l)}{\boldsymbol{a}(\hat{u}_l)^H\boldsymbol{R}_{zz}^{-1}\boldsymbol{a}(\hat{u}_l)} \qquad \left(\boldsymbol{w}(\hat{u}_l)^H\boldsymbol{a}(\hat{u}_l) = 1\right) \tag{6}$$

$$\boldsymbol{a}(\hat{u}_l) = \left[1,\ \exp\left(-j\frac{2\pi}{\lambda}d\hat{u}_l\right),\ \cdots,\ \exp\left(-j\frac{2\pi}{\lambda}(K-1)d\hat{u}_l\right)\right]^T \tag{7}$$

Here, $\hat{u}_l = \sin\hat{\theta}_l$, and $\boldsymbol{a}(\hat{u}_l)$ is the array response vector with the phase reference at the 1st antenna element. Also, $\boldsymbol{R}_{zz}$ is the covariance matrix based on estimation of previous iteration and in this case it is made up as

$$\boldsymbol{R}_{zz} = \sum_{l=1}^{L}\boldsymbol{a}(\hat{u}_l)\boldsymbol{a}(\hat{u}_l)^H + \alpha\boldsymbol{I} \tag{8}$$

where α is a small positive number (pseudo noise power) for $\boldsymbol{R}_{zz}$ to be non-singular. Using $\boldsymbol{w}_l$ yields an array pattern with the mainlobe in the direction of the lth wave and nulls in the other waves. In addition, it is possible to control the whole ability of creating nulls by adjusting α in Eq.(8). For example, small value of α gives deep nulls, while large value of α contributes to making almost only mainlobe.

When the number of beams formed for the lth incoming wave is four, for example, the beamforming matrix $\boldsymbol{W}_l$ is constructed as follows by using the weight vector $\boldsymbol{w}_l$.

$$\boldsymbol{W}_l = \left[\boldsymbol{w}_{ln}\left(\hat{u}_l - \frac{3}{K}\right), \boldsymbol{w}_{ln}\left(\hat{u}_l - \frac{1}{K}\right),\ \boldsymbol{w}_{ln}\left(\hat{u}_l + \frac{1}{K}\right),\ \boldsymbol{w}_{ln}\left(\hat{u}_l + \frac{3}{K}\right)\right] \tag{9}$$

In Eq.(9), $\boldsymbol{w}_{ln}$ stands for the normalized $\boldsymbol{w}_l$ with $\|\boldsymbol{w}_l\|$.

4. Performance Analysis by Computer Simulation

Under conditions shown in Tables 1 and 2, the computer simulation is carried out to clarify the performance of the proposed algorithm. Also, the spatial smoothing processing is utilized for getting the covariance matrix. For DOA and AS estimation, the proposed method based on the beamspace MUSIC algorithms is used. The proposed method iteratively estimates the DOA and AS until they converge. In this simulation, the maximum iteration number is 30. As an example, the beamspace MUSIC spectrum is shown in Figs.2 and 3, and the beam pattern is shown in Fig.4. The results of estimation are given in Table 4. In the case of 2 wave clusters incident, we can see the effectiveness of estimating DOA and AS by making 2 peaks of the MUSIC spectrum in each direction of wave clusters. Although actual AS of both incoming wave clusters is 10°, the result of AS estimation is 5.00° and 6.75°, which still remains to improved.

Next, under conditions shown in Tables 1 and 3, the computer simulation is carried out. As the evaluation measure of estimated results, RMSE (root mean square error) is used, which is calculated through 100 independent trials. In this simulation, the DOA of the 1st wave cluster is varried from −20° to 10°. From Figs.5 and 6, it is observed that the proposed method using the beamspeace MUSIC algorithm can estimate DOAs of 2 wave clusters more accurately than the method using ordinary MUSIC algorithm. Therefore, we can confirm that the proposed method is available and useful.

Table 1: Simulation conditions.

Array configuration	Uniform linear array of isotropic elements
Element spacing	0.5λ
Number of elements	10
Number of subarray elements	8
Number of beams	4
Number of wave clusters	2
Number of elementary waves	30
Power distributions of cluster	Uniform distribution
SNR	20dB

Table 2: Radio environment 1.

DOA (1st, 2nd)	(−10°, 35°)
Initial value of DOA(1st, 2nd)	(−15°, 40°)
AS of incoming cluster(1st, 2nd)	(10°, 10°)
Initial value of AS(1st, 2nd)	(0°, 0°)

Table 3: Radio environment 2.

DOA(1st, 2nd)	(−20° to 10°, 35°)
Initial value of DOA of the beamspace MUSIC(1st, 2nd)	(−25° to 5°, 40°)
AS of incoming cluster(1st, 2nd)	(10°, 10°)
Initial value of AS of the beamspace MUSIC(1st, 2nd)	(0°, 0°)

Table 4: Results of DOA and AS estimation.

Result of DOA estimation(1st, 2nd)	(−9.85°, 35.075°)
Result of AS estimation(1st, 2nd)	(5.00°, 6.75°)

5. Conclusion

In this paper, we have proposed the simple DOA and AS estimation method based on the beamspace MUSIC algorithm with the DCMP beamformer. Via computer simulation, we have shown that the proposed method can obtain simply the DOA and AS of incoming wave clusters in comparison with the ordinary MUSIC algorithm. As the future work, we will try to estimate DOA and AS more accurately when 2 wave clusters are incoming closely.

References

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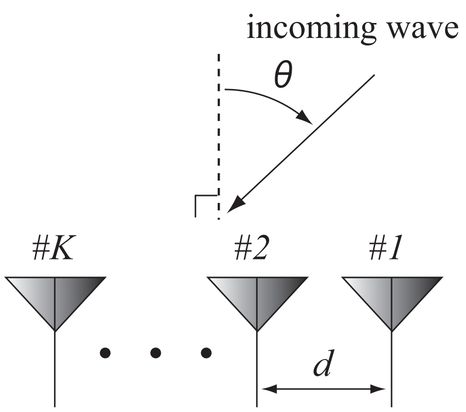

Figure 1: *K*-element uniform linear array. (element spacing: *d*)

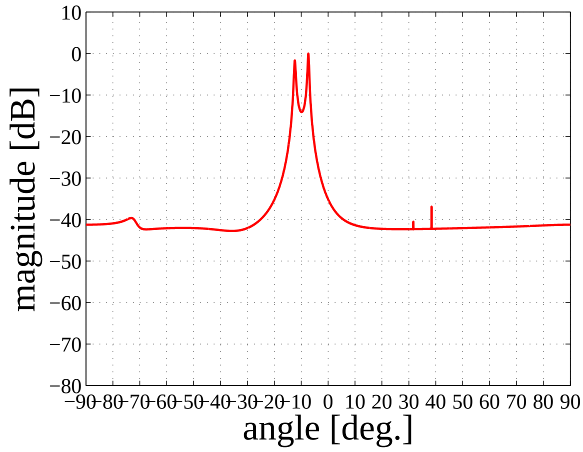

Figure 2: Beamspace MUSIC spectrum to estimate DOA and AS of 1st incoming wave cluster.

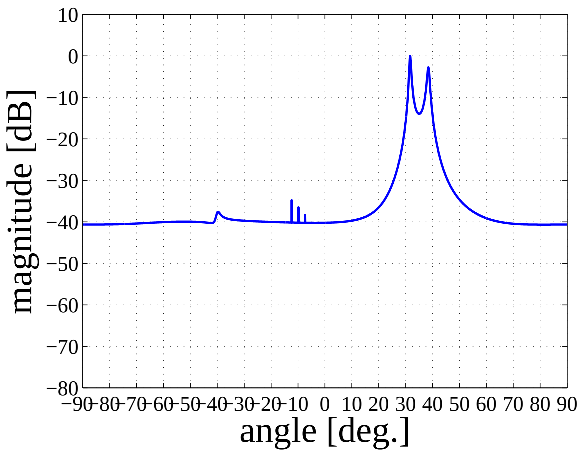

Figure 3: Beamspace MUSIC spectrum to estimate DOA and AS of 2nd incoming wave cluster.

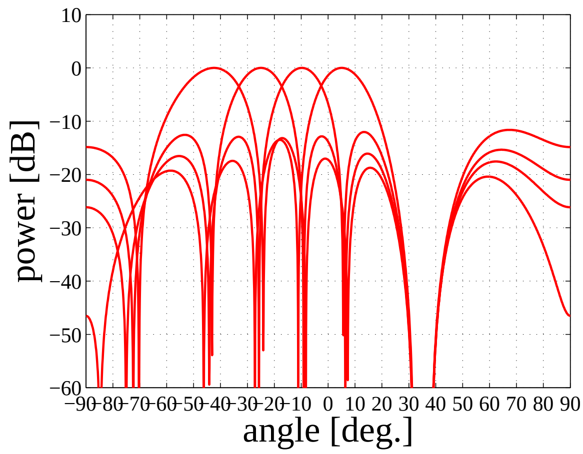

Figure 4: Multibeam patterns using DCMP to estimate DOA and AS of 1st incoming wave cluster.

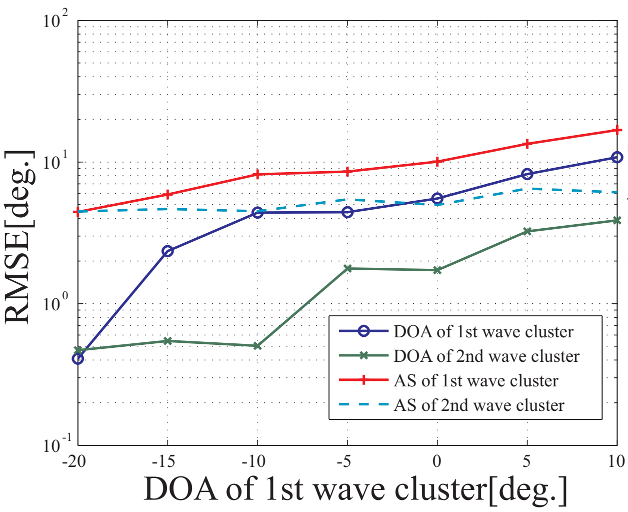

Figure 5: RMSE of DOA and AS estimates by using the MUSIC algorithm.

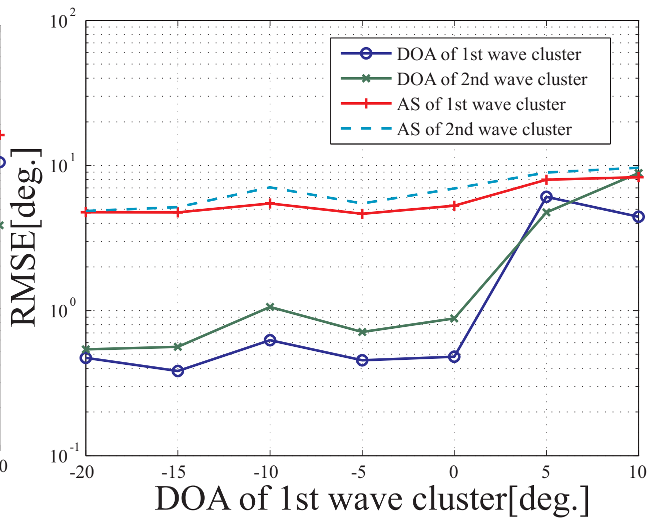

Figure 6: RMSE of DOA and AS estimates by using the beamspace MUSIC algorithm.