ROBUST 2D-DOA ESTIMATION USING THE DIFFERENCE OF 2 MODEVECTORS

Hiromi MATSUNO, Hiroyuki ARAI
Department of Electrical and Computer Engineering, Yokohama National University
79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan.
E-mail: h-matzno@arailab.dnj.ynu.ac.jp

1 INTRODUCTION

DOA estimation using array antenna has been investigated and developed in wireless communication techniques. It is applied in many systems such as propagation prediction and radar systems [1]. In many cases, the former is the application in multipath environments and the latter is in comparatively static circumstances. The problem is that the systems contain performance degradation factors though superresolution algorithms such as MUSIC and ESPRIT enable it to estimate DOAs with high accuracy. The performance degradation is caused by many factors such as mutual coupling and amplitude and phase error between each port of array. How to compensate them is one of the most interesting topics recently. Array calibration is effective and many calibration techniques have been proposed. Calibration technique based on universal steering vector [2] and reference signals [3] are well-known and they estimate DOAs with high accuracy. On the other hand, these techniques require independent complex calculation for each array antenna. These calibration techniques tend to be complex, especially in 2-dimensional (2D)-DOA estimation systems.

Authors in this paper proposed 1D-DOA estimation system based on virtual modevector. It is composed by 2 modevecors based on uniform linear array (ULA) [4]. Assuming 2 modevectors have difference in their element spacings, the element spacing of virtual modevector is equivalent to the difference between each element spacing. Therefore, this technique suppresses grating lobes due to large element spacing. Setting the difference between element spacings to half wavelength with large element spacings, we obtain virtual half-wavelength modevevtor whose mutual coupling is weak. Moreover, this technique eases the influence of amplitude and phase error between each port of array antenna and achieves robustness against error factors.

In this paper, we expand the proposed technique to 2D-DOA estimation. Calibration-free 2D-DOA estimation system is achieved in similar way. We verify the proposed technique with experiment in anechoic chamber and indoor circumstance. This technique does not apply to estimation in multi-incident wave circumstance because it requires to obtain modevector. Therefore, the usage is limited to the application in single incident wave circumstances such as the estimation of specific target in radar systems. On the other hand, this technique has the advantage to avoid complex array calibration.

2 DEFINITION of MODEVECTOR and PROPOSED TECHNIQUE

In this section, we define modevector and explain about proposed technique in detail. We assume the received array as K element with arbitrary geometry array as shown in Fig.1 a). The modevector of k-th element (allocated $\mathbf{r_k} = (x_k, y_k, z_k)$) for the incident angle of (θ, ϕ) is described as follows,

$$a_k(\theta,\phi) = exp\{j\frac{2\pi}{\lambda}\mathbf{r_k}\mathbf{L}(\theta,\phi)^H\} \quad (1)$$

$$\mathbf{L}(\theta,\phi) = [sin\theta cos\phi, sin\theta sin\phi, cos\theta] \quad (2)$$

where λ is wavelength and $\mathbf{L}$ denotes look direction vector. The phase reference is set to $\mathbf{r_o}(0,0,0)$. Modevector is a complex vector defined with element allocation, frequency, and incident angle. Therefore, the ratio of 2 different modevectors is the complex vector based on the difference of phase of each modevector. In the case of 2 modevectors having difference in their element allocations $(\mathbf{r_{1k}}, \mathbf{r_{2k}})$, the difference of each modevector is described as follows,

$$a_{Dk}(\theta,\phi) = \frac{a_{1k}}{a_{2k}} = exp\{j\frac{2\pi}{\lambda}(\mathbf{r_{1k}} - \mathbf{r_{2k}})\mathbf{L}(\theta,\phi)^H\} \quad (3)$$

It is equivalent to the modevector of the element allocation of $(\mathbf{r_{1k}} - \mathbf{r_{2k}})$. This virtual modevector does not depend on the actual element allocation. By setting the difference of element allocation appropriately, grating lobes due to large element spacing is suppressed. On the other hand, the influence of mutual coupling is eased with large element spacing. Therefore, this technique provides the virtual modevector which does not suffer from mutual coupling. Then the persisting error on array antenna is considered as amplitude and phase error between each port. They are described as multiplying to the modevector directly. Assuming the amplitude and phase error on k-th element α_k, β_k, the modevectors are replaced.

$$a'_k(\theta,\phi) = \alpha_k exp\{j\beta_k\}a_k(\theta,\phi) \quad (4)$$

$$a'_{Dk}(\theta,\phi) = \frac{\alpha_{1k}}{\alpha_{2k}} exp\{j(\beta_{1k} - \beta_{2k})\}a_{Dk}(\theta,\phi) \quad (5)$$

It indicates that the ratio of amplitude error and the difference of phase error of 2 modevectors influence the DOA estimation accuracy. By setting the deviation of amplitude and phase error between 2 arrays small, the influence of error is also eased. The robustness against performance degradation factors is achieved. This technique requires to extract modevectors from the received signals. Assuming a single incident wave circumstances, the signal subspace of received signal is equivalent to the modevector. Moreover, the covariance matrix of virtual array is obtained by calculating the ratio of the element of 2 covariance matrices. On the other hand, it is difficult to extract modevectors from received signal in a multi-incident wave circumstances. In this paper, we assume a single incident wave circumstances. We apply MUSIC algorithm to estimate DOA in order to verify grating lobe suppression.

3 EVALUATION by CALCULATION

The proposed technique is evaluated by calculation in this section. We assume 2 received arrays as 4 elements uniform rectangular array (URA) shown in Fig.1 b) and their element spacings are $d_1 = 2.45\lambda$ and $d_2 = 2.00\lambda$, respectively. The element spacing of virtual URA is 0.45λ. Mutual coupling is neglected and the amplitude and phase error between each port (α_k, β_k) are given at random whose average and variance are 0 and 1, respectively. At first, we consider the error factor of array 2 is equivalent to that of array 1($\alpha_1 = \alpha_2$, $\beta_1 = \beta_2$). Figure 2 shows MUSIC spectrum of proposed array and URA($d = d_1$). The MUSIC spectrum of URA without error factor (or completely calibrated) has grating lobes due to large element spacing(Fig.2 a)). Moreover, the spectrum with error factor is degraded(Fig. 2 b)). On the other hand, the proposed array suppresses grating lobes and does not suffer from performance degradation factors.(Fig. 2 c)) Next, we consider the deviation of error factor between array 1 and array 2. We set the amplitude and phase error of array 2 as $\alpha_2 = \alpha_1(1+\delta)$, $\beta_2 = \beta_1(1+\gamma)$, where δ and γ are random value whose average and variance are 0 and σ^2, respectively. Figure 3 shows the estimation error due to the deviation of α, β. The solid line represents the 1D-DOA estimation error of virtual ULA whose element spacing is 0.5λ. The dotted line, broken line, chain line show the 2D-DOA estimation error of virtual URA. In the case of 1D, the phase and amplitude error is suppressed within 25% error deviation. On the other hand, 2D is more sensitive to the error deviation and the accuracy depends on incident angle. This result indicates

Table 1: Experiment Specifications

Array shape	4 elements URA	Radio frequency	2035MHz
d_1	2,17λ	Intermediate Frequency	10MHz
d_2	1.70λ	Sampling Frequency	40MHz
Power	0 dBm	snapshots	2000

that the deviation of each error should be small in order to obtain robust 2D-DOA estimation. The amplitude and phase error between each port is caused by the difference of element, port of receiver, and the configuration of cables. How to obtain small error deviation between each array is important factor.

4 EVALUATION by MEASUREMENT

In this section, we show the measurement results in anechoic chamber and indoor circumstance. We useed 4 elements rectangular array and changed its element spacing physically in order to obtain 2 received array. Configured with the same feed circuit, small error deviation model is expected. Table 1 shows the experiment specifications. The measurement results in anechoic chamber is shown in Fig.4. These results required to adjust the amplitude and phase error between each port because the error factor changed due to the change of cable configuration and element allocation error. These results show that the proposed technique suppresses grating lobes but the influence of large error deviation degrades the estimation accuracy. How to obtain small error deviation is the problem to obtain robustness against error.

Next, we show the estimation results in indoor circumstance as shown in Fig.6. In order to obtain the robustness, we cared the configuration of cables and element allocation. The received array is set in the front of transmitting antenna and expected incident angle is $\theta = 0^\circ$ (ϕ has no value). Figure 6 a) and b) show the MUSIC spectrum of URA ($d = d_2$), and proposed array, respectively. The estimation results of the proposed array suppresses the grating lobes and it has a peak on $\theta = 0^\circ$. On the other hand, the spectrum is not as sharp as calculation results. It is also considered due to large error deviation.

5 CONCLUSION

In this paper, we proposed a robust 2D DOA estimation system. The virtual modevector based on 2 modevectors suppresses grating lobes due to large element spacing. The influence of mutual coupling is neglected with large element spacing. In addition, the amplitude and phase error between each port is eased with the process. In the case of 1D-DOA estimation, the error deviation is eased within less than 25%. On the other hand, 2D-DOA estimation is more sensitive to error deviation and how to obtain small error deviation of 2 array is the important factor. In the experiment, we achieved robust 2D-DOA estimation with variable element spacing URA. The experiment in anechoic chamber and indoor circumstance verified the system.

References

[1] N.Kikuma, "ADAPTIVE SIGNAL PROCESSING with Array Antenna," Sciene and Technology Publishing Company, Japan 1999.

[2] Q. Yuan, et al.,In:IEICE Trans. Commun., vol. E91-B, no.5 pp.1575-1580, May 2008

[3] T.Arai, et al., In:IEICE Trans, A.P., vol. J8-B, no.3 pp.527-535, May.2002.

[4] H. Matsuno and H. Arai, "Calibration-free DOA estimation by the differential array antenna," ISAP2006 TD-2.

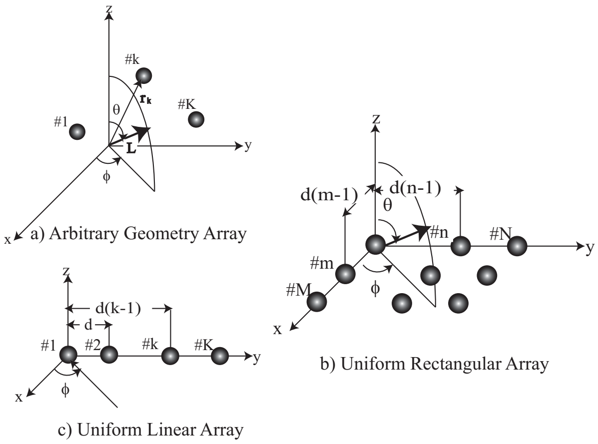

Figure 1: Array shapes

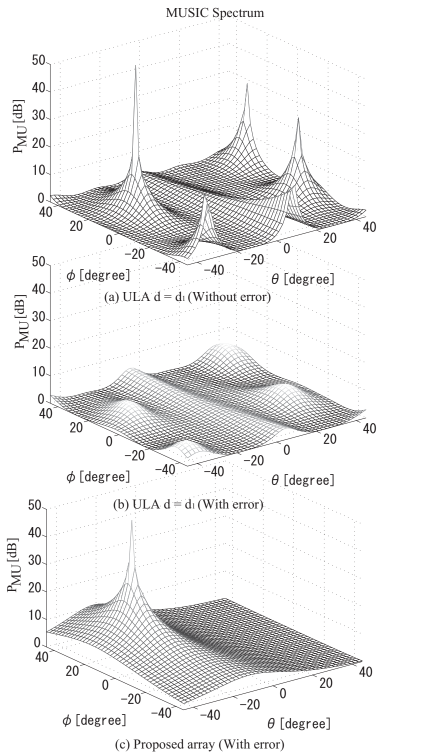

Figure 2: 2D DOA estimation results

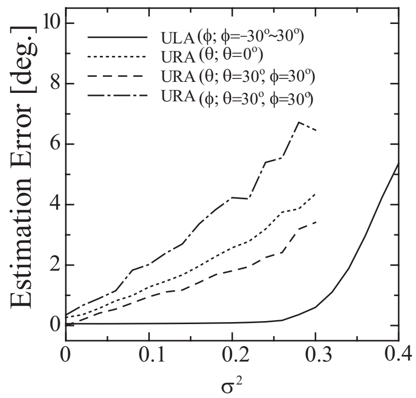

Figure 3: Estimation Error due to Error Deviation

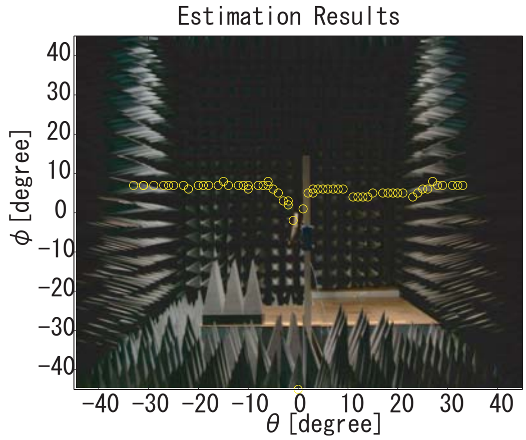

Figure 4: Experiment in anechoic chamber

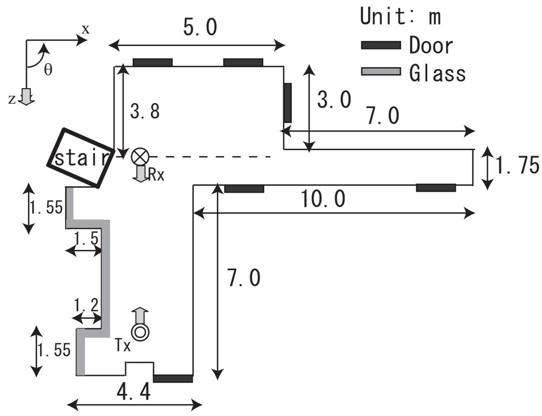

Figure 5: Indoor Circumstance for experiment

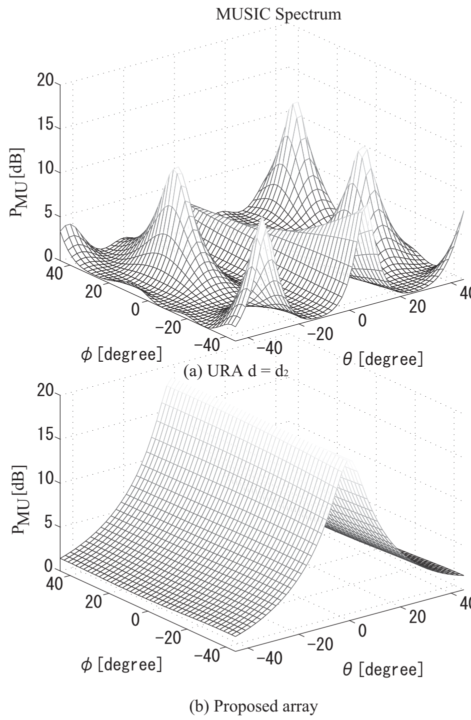

Figure 6: array antenna for experiment