Sub-band processing for DOA estimation of UWB signal

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Abstract: In this paper, sub-band technique to reduce the effect of antenna pattern distortion is proposed. In the proposed scheme, received wideband signal is divided into several frequency bands and DOA is estimated in the respective frequency bands. By averaging the estimated results, the effect of antenna pattern distortion will be reduced. Numerical results shows that the DOA estimation accuracy is improved by the proposed sub-band signal processing.

Keywords: DOA, estimation, sub-band, signal processing

Classification: Antennas and Propagation

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1 Introduction

High resolution method for direction of arrival (DOA) estimation using array antenna is studied actively [1]. In almost previous studies, it is assumed that the antenna elements have the same directional patterns. However, it is very difficult to make many antenna elements they have just the same directional patterns. Furthermore, the directional patterns are distorted due to mutual coupling between the antenna elements [2]. The estimation accuracy is decayed if the directional patterns are distorted intensively. Generally, to

avoid the effect of directional pattern distortion, antenna characteristics are calibrated before the estimation, however, it is difficult to cancel the effect of distortion when the arrival signal is very wideband because the directional patterns depend on the frequency.

In this paper, sub-band technique to reduce the effect of antenna pattern distortion is proposed [3]. In the proposed scheme, received wideband signal is divided into several frequency bands and DOA is estimated in the respective frequency bands. By averaging the estimated results, the effect of antenna pattern distortion will be reduced. In the following section, configuration of proposed system is explained first. Next, the effect of number of sub-band and effect of antenna characteristics on DOA estimation accuracy is discussed.

2 DOA estimation without antenna calibration

Figure 1 shows the signal flow of proposed scheme. Here, we propose two sub-band technique; one is “Spectrum Averaging Method” and another is “Beam Averaging Method.” The scheme of respective method is as follows.

a) Spectrum Averaging Method:

The signals received by the antennas are divided into n frequency sub-bands by using band-pass filters (BPFs). The MUSIC method [4] is applied to respective sub-band, and then the MUSIC spectrums are averaged. Examples of “Spectrum Averaging Method” are drawn in Fig. 2 (a) and (b).

Condition of simulation is as follows; Frequency: 3-8 GHz, Antenna array: 6 element linear array, element space: 5 cm (0.5 wavelength at 3 GHz), No. of arrival wave: 1 wave, DOA: 30 deg., No. of sub-bands: 8 sub-band.

Figure 2 (a) shows the examples of MUSIC spectrum in the respective frequency band. We can see that several peaks of MUSIC spectrum due to ambiguity of direction are observed. Moreover, the direction of unnecessary peaks are different each other because the element distance in wavelength depends on the sub-band frequency. The averaged MUSIC spectrum is shown in Fig. 2 (b). By averaging the plural MUSIC spectrums, only one peak is remained and the others are disappeared.

b) Beam Averaging Method:

The signals received by the antennas are divided into n frequency sub-bands as the same as the “Spectrum Averaging Method.” Then, Beamformer method [5] is applied to the respective band and the outputted beams from the beamformers are averaged. Examples of the “Beam Averaging Method” are shown in Fig. 2 (c) and (d). The condition is the same with Fig. 2 (a) and Fig. 2 (b). Figure 2 (c) shows the results of respective beamformer and Fig. 2 (d) is the averaged result. As we can see that many grating lobes are observed in Fig. 2 (c), however, only one beam is observed in Fig. 2 (d). In the “Beam Averaging Method”, there is no singular value decomposition. Thus, the calculation load is much less than that of “Spectrum Averaging

Fig. 1. Signal flow of proposed DOA estimation methods

Fig. 2. Examples of MUSIC spectrum and Beam

Method.”

3 Model of directional pattern distortion

The effect of distortion of element pattern is evaluated through computer simulation in the following section. The amplitude and phase of element pattern, $G(\theta)$ and phase $\angle G(\theta)$ is modeled as Eqn. (1) and Eqn. (2), respectively.

$$G(\theta) = G_0(\theta) \cdot \left| 10^{\frac{\Delta G_a(\theta)}{20}} \right| \quad [\text{dB}] \quad (1)$$

$$\angle G(\theta) = \Delta\theta \cdot (\pi/180) \quad [\text{rad}] \quad (2)$$

Here, $G_0(\theta)$, $\Delta G_a(\theta)$ and $\Delta\theta$ is the original directional pattern, amplitude error and phase error due to the distortion, respectively. In this letter, it is assumed that “Amplitude error” and “Phase error” follows log-normal distribution and normal distribution, respectively.

4 Improvement of DOA estimation accuracy

4.1 Effect of number of sub-band on estimation accuracy

Figure 3 (a) shows the relation between number of sub-band and DOA estimation accuracy. The conditions of the simulations are the same as that of Fig. 2, except for number of sub-band. Deviation of $\Delta G_a(\theta)$ and $\Delta\theta$ is set at 15 dB and 0 degree. The vertical axis shows the average error in 100 trials. It is found that the estimation accuracy is improved as the number of sub-band is increased. But, the amount of improvement is saturated even if the signal is divided into a lot of sub-band. It seems that the appropriate number of sub-band is around eight. It is also found in the figure that the accuracy of “Spectrum Averaging Method” is superior to that of “Beam Averaging Method.” The difference of the accuracy comes from original performance between MUSIC algorithm and Beamformer method.

(a) Effect of sub-band number

(b) Effect of amplitude error

(c) Effect of phase error

Fig. 3. Improvement of DOA Estimation Accuracy

4.2 Improvement of estimation accuracy by sub-band processing

Figure 3 (b) shows the effect of amplitude error of antenna element pattern on DOA estimation accuracy. Here, phase error is set as 0 degree. We can see in the figure that the estimation error in case of “Spectrum Averaging Method” is greatly improved compared with original MUSIC method. On the other hand, the accuracy of “Beam Averaging Method” is inferior to

that of “Spectrum Averaging Method.” This is because of the difference of original performance between MUSIC algorithm and Beamformer method.

The effect of phase error of element pattern on estimation accuracy is shown in Fig. 3 (c). Here, the amplitude error is set as 0. In Fig. 3 (c), the estimation error is linearly increased with the phase error. The accuracy of “Beam Averaging Method” is almost the same with “Spectrum Averaging Method” even the calculation cost is much smaller. Thus, we can say that the “Beam Averaging Method” is suitable for compensate the phase error of antenna elements.

5 Conclusion

In this paper, two types of sub-band technique to decrease the effect of antenna pattern distortion were proposed and evaluated; one was “Spectrum Averaging Method” and another was “Beam Averaging Method.” As the results, it was clarified that the estimation accuracy was greatly improved by “Spectrum Averaging Method”. It was also found that the accuracy of “Beam Averaging Method” was almost the same with “Spectrum Averaging Method” for phase error. Thus, the “Beam Averaging Method” is suitable for compensate the phase error of antenna elements.