Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

Direction of arrival estimation on unevenly-spaced single-channel microphone array

不等間隔単一チャネルマイクロフォンアレーによる到来方向推定

Keiichi Zempo†, Kazuki Suemitsu, Koichi Mizutani, and Naoto Wakatsuki (Univ. Tsukuba)
善甫 啓一[1†], 末光 一貴[2], 水谷 孝一[1], 若槻 尚斗[1] ([1]筑波大・シス情系, [2]筑波大院・シス情工)

1. Introduction

A number of the array signal processing on microphone array were carried out to estimate the direction-of-arrival (DOA) or enhance / separate the sound source for many years[1, 2]. Contrastly to this array signal processing offers a number of input channel, the opportunities of it recorded on a few input channel devices (*e.g.* Smartphones) are expanding in these years. Unfortunately, multi-channel recording for array signal processing is difficult for these cases, because these devices are usually equipped with monaural or stereo input. Moreover, such as networked-recording is conceivable for multi-channel recording, the clock synchronization accuracy is not enough for array signal processing that offers the accurate time of the difference between the elements of the microphone array.

For these reasons, we propose the single-channel microphone array (SCMA) to achieve the array signal processing on a few input channel devices, in this paper. This SCMA outputs the summation of the signals received at the constitutive microphones. The output signal of the SCMA is echoed intentionally, to discriminate the DOA of the sound source. The purpose of this paper is to analyze the beam pattern generated by SCMA and the accuracy of DOA estimation on SCMA. Additionally, the layout effect of the constitutive microphones was validated.

2. Direction of arrival estimation on single-channel microphone array

The received signal through SCMA would be the delayed summation of the target sound signal such as the MISO (Multiple Input, Single Output) signal on a field of radio communication[3]. In the proposing method, we gain the extracted sound signal, $s_{\mathrm{SCMA};\theta}(t)$, corresponds to the angle, θ, by applying the inverse FIR (Finite Impulse Response) filter[4] calculated by the profiles of FIR for each angle, $h(t,\theta)$, which were recorded preliminarily. Consequently, the DOA would be estimated as,

$$\theta_{\mathrm{est}} = \arg_{\theta} \max \left(\sum_t \left| s_{\mathrm{SCMA};\theta}(t) \right|^2 \right) . \qquad (1)$$

Figure 1 shows the schematic diagram of the proposed method. Arbitrary number and layout of the microphones, which consists SCMA, are available. Especially, unevenly-spaced layout is except to suppress the side lobes.

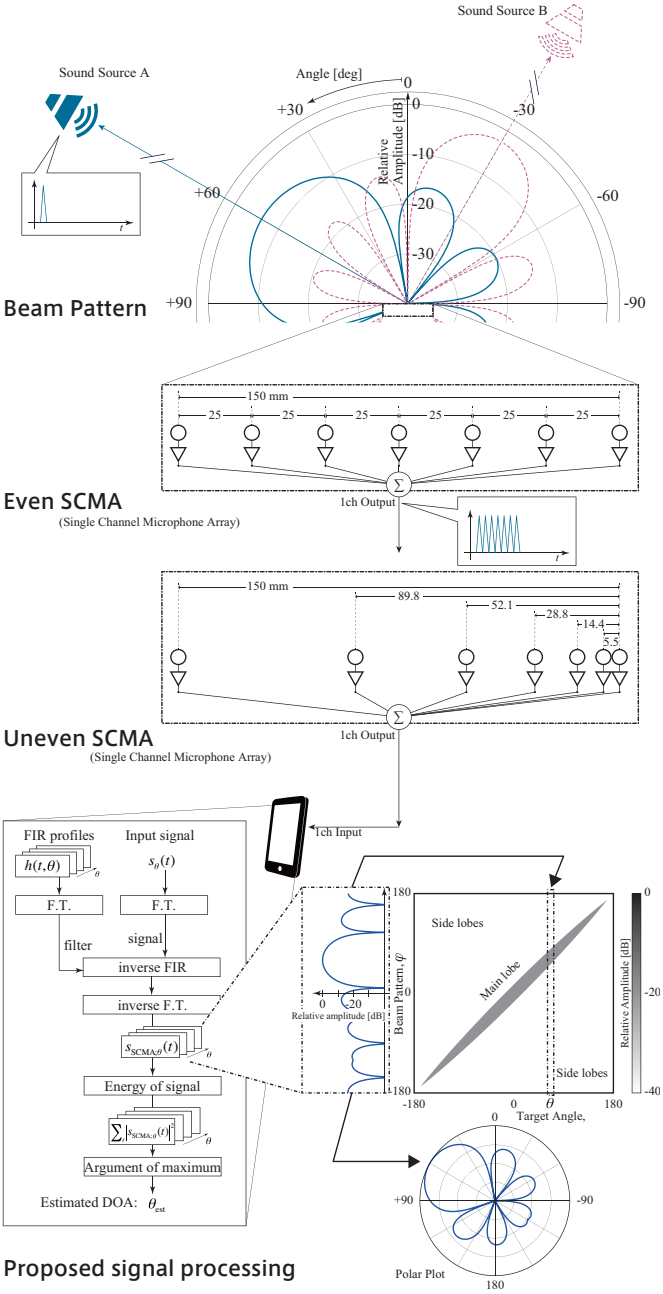

Fig. 1 Schematic diagram of DOA estimation on single-channel microphone array

zempo@iit.tsukuba.ac.jp

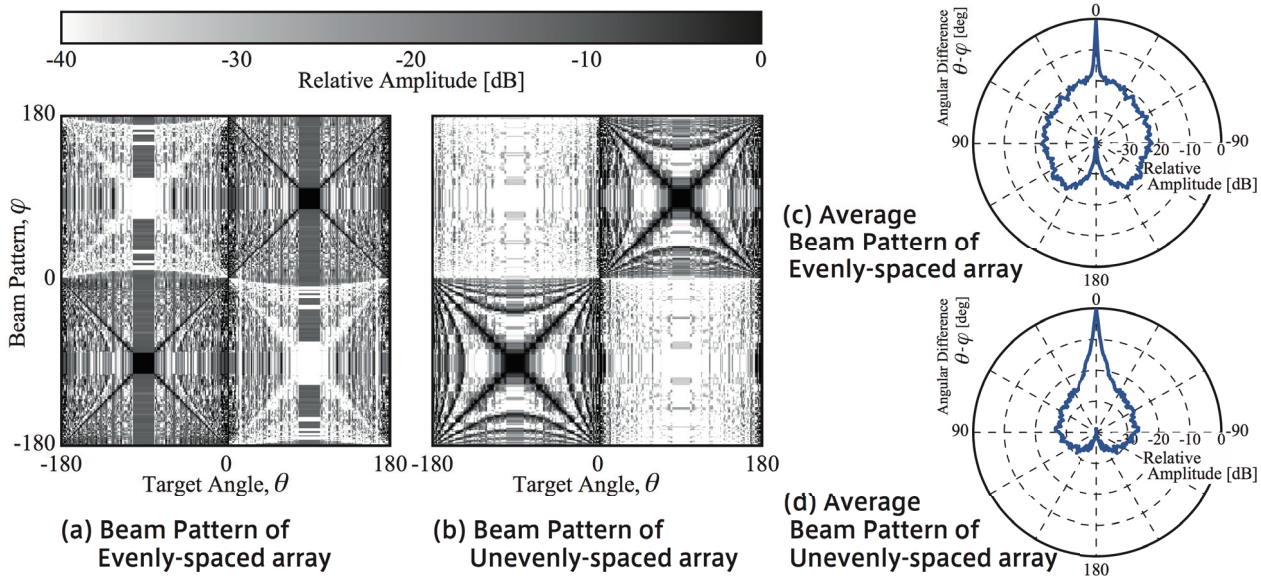

Fig. 2 Evaluation result of the Single-channel Microphone Arrays

(a) The beam patterns of the Evenly-spaced array to each target angle, **(b)** The beam patterns of the Unevenly-spaced array to each target angle, **(c)** The beam patterns of the Evenly-spaced array averaged by each target angle, **(d)** The beam patterns of the Unevenly-spaced array averaged by each target angle

3. Evaluation

To analyze the beam pattern, we had recorded the profiles of FIR for each angle, $h(t,\theta)$, through numerical experiments. Also the accuracy of DOA estimation provided by the proposed method was evaluated for the each SCMA. **Table 1** shows the experimental conditions. Two SCMA layouts were evaluated which were shown in Fig. 1.

Figure 2 shows the result of the analysis. Through the results, we could confirm that the directivities were formed for both SCMA by the proposed method. **Table 2** shows the parameters of main lobe behavior by fitting Gaussian on an average beam pattern. Although the evenly-spaced SCMA has sharp main lobe, unevenly-spaced SCMA perform better in the sake of suppressing the side lobes. **Table 3** shows the accuracy of the DOA estimation. From the results, we could find the advantages of the unevenly-spaced SCMA.

Table 1 Experimental parameter

Number of microphones	7
Maximum base length	150 mm
Sampling frequency	96 kHz
Sonic velocity	340 m/s
Sound source	Up-chirp (0--48 kHz)
Angular step of $h(t,\theta)$	1 deg

Table 2 Analysis result of the beam patterns

	Evenly	Unevenly
Half Power Beam Width	0.83 deg	4.44 deg
Average Ratio of Main Lobe to Side Lobes	20.4 dB	24.5 dB

Table 3 Accuracy of the DOA estimation

Error Margin	Evenly	Unevenly
Within ±1 deg	22.8 %	23.3 %
Within ±3 deg	66.1 %	79.4 %
Within ±5 deg	81.4 %	90.0 %

4. Conclusion

In this paper, we developed the array signal processing for SCMA with the aim of applying it on a few input channel devices. The beam pattern and the accuracy of DOA estimation on SCMA were evaluated. Thorough the experiments, we confirmed the directivities were formed on the beam pattern and DOA estimation was available in proposed method. Additionally, we also confirmed the advantages of unevenly-spaced SCMA.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 151C20886.

References

1. J. Yamamoto *et.al.*: Jpn. J. Appl. Phys. **54** (2015) 07HE16.
2. S. Tamano *et.al.*: Jpn. J. Appl. Phys. **54** (2015) 07HF24.
3. J. Xiong *et.al.*: IEEE Trans. Broadcasting **59** (2012), 116.
4. D. Murphy *et.al.*: Appl. Acoust. **82** (2014), 6.