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Microphone Array with Variable Directional Characteristic Pattern based on Phase Difference Information
位相差情報に基づく指向特性可変マイクロフォンアレイ

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1. Introduction

In resent years, the microphone array has been used for estimating Direction of Arrival (DoA)[1,2]. Mainly method is to extrapolate direction from sound delay and positional relation between each microphone. This system is meanful for some kind of the monitoring, detecting abnormal sound in plant, or sound receiving without hand[3]. Though, there are some tecniques to enhance the sound from specified direction[4] after estimating DoA, the sidelobes with same level to mainlobe will appear by each frequency. This paper describes about sidelobe suppression based on the phase gap of noise sound. Also, simulation on enhancing the sound from specified direction is compared with delayed-sum method. This is an ususal method to enhancing the specified direction sound.

2. Estimating Delay of Arrival

In this paper, we focus on a case that there are two sound sources; a signal source and a noise source. The microphone array does not have information on the sound source directions. The array is organized with two microphones. Delay of arrival between two microphones occurs because of speed finiteness of sound transmitting. After estimating DoA for each of signal, adjusting the observed signals shifted, makes a variable directional characteristic of between each microphones. The relation of the delay of arrival and the direction is shown with eq. (1) and **Fig. 1**.

$$\theta = \sin^{-1}\left(\frac{c\tau}{d}\right), \tag{1}$$

where, θ is direction from center of array, d is distance between microphones, c is sonic speed, τ is delay of arrival. We use CSP (Cross–power Spectrum Phase) analysis to estimate τ. A CSP function, $R_{\mathrm{CSP}}(t)$ is given by

$$R_{\mathrm{CSP}}(t) = \mathcal{F}^{-1}\left(\frac{\mathcal{F}\big(s_1(t)\big)\cdot\mathcal{F}\,\big(s_2(t)\big)}{\big|\mathcal{F}\big(s_1(t)\big)\big|\cdot\big|\mathcal{F}\big(s_2(t)\big)\big|}\right), \tag{2}$$

where $s_1(t)$, $s_2(t)$ denote observed signals by microphone, $\mathcal{F}(u)$ and $\mathcal{F}^{-1}(u)$ denote Fourier transform and inverse transform of u, and $\mathcal{F}^*(u)$ denotes complex conjugation of $\mathcal{F}(u)$. The delay of arrival for target signal and noise signal are expressed as τ_1 and τ_2 is where, $R_{\mathrm{CSP}}(t)$ marks the most and 2ndly high value.

$$\tau_1 = \arg_t \max\big(R_{\mathrm{CSP}}(t)\big)\,. \tag{3}$$

$$\tau_2 = \arg_t \max\,(R_{\mathrm{CSP}}(t); t \neq \tau_1)\,. \tag{4}$$

3. Enhancing the Target Sound

By point of view from each frequency, delayed sum method has strong sidelobes. Therefore, we propose the geometric method in complex plane based on phase gap estimated from delay of arrival for each frequency to enhance the target sound. The observed signals: $s_1(t)$ and $s_2(t)$ could be describe as summation of target signal:$s_s(t)$ and noise signal: $s_n(t)$.

$$s_1(t) = s_s(t) + s_n(t)\,. \tag{5}$$

$$s_2(t) = s_s(t-\tau_1) + s_n(t-\tau_2)\,. \tag{6}$$

If we shift the signal to adjust with target signal,

$$s_2(t+\tau_1) = s_s(t) + s_n(t+\tau_1-\tau_2)\,. \tag{7}$$

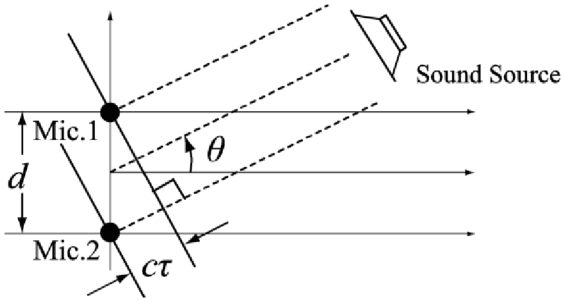

Fig. 1 Relation of direction of sound source and microphone array

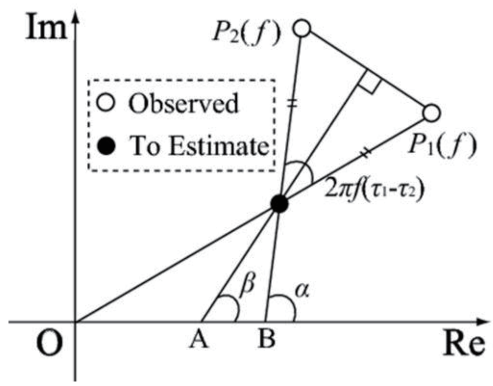

Fig. 2 Location of $S_s(f), P_1(f)$ and $P_2(f)$

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Define $P_1(f), P_2(f)$ where we already used in eq.(2),

$$P_1(f) \equiv \mathcal{F}(s_1(t)) = S_s(f) + S_n(f)\,, \tag{8}$$

$$P_2(f) \equiv \mathcal{F}(s_2(t+\tau_1)) = S_s(f) + S_n'(f)\,. \tag{9}$$

Where, $S_s(f) \equiv \mathcal{F}(s_s(t)), S_n(f) \equiv \mathcal{F}(s_n(t))$, f is frequency, and $S_n'(f)$ denotes $\mathcal{F}(s_n(t+\tau_1-\tau_2))$. **Fig. 2** shows location of these points on complex plane. If we approximate $|S_n(t)|$ does not change in $\tau_1-\tau_2$, triangle $S_sP_1P_2$ should be isosceles triangle in condition of $S_sP_1 = S_sP_2$. And considering the phase gap of noise,

$$\angle P_1S_sP_2 = 2\pi\nu(\tau_1-\tau_2)\,. \tag{10}$$

$\angle\alpha$ and $\angle\beta$ could be calculated as,

$$\angle\alpha = \beta - \pi\nu(\tau_1-\tau_2)\,, \tag{11}$$

$$\angle\beta = \tan^{-1}\left(\frac{\mathrm{Im}(P_1)}{\mathrm{Re}(P_1)}\right) + 2\pi\nu(\tau_1-\tau_2)\,. \tag{12}$$

$\mathrm{Re}(c)$ and $\mathrm{Im}(c)$ denotes real and imaginary part of complex number c, respectively. Hence, we can obtain S_s with calculating intersection point of line AS_s and BS_s.

By Defining x, y as unit vector of real and imaginary part, line AS_s and line BS_s will be,

$$y = (\tan\alpha)x + \frac{1}{2}\mathrm{Im}(P_1+P_2) - \frac{1}{2}\mathrm{Re}(P_1+P_2)\tan\alpha\,, \tag{13}$$

$$y = (\tan\beta)x + \mathrm{Im}(P_2) - \mathrm{Re}(P_2)\tan\beta. \tag{14}$$

Therefore, we can obtain the enhanced target signal.

4. Simulation

We simulated proposed method and delayed-sum method aimed at target sound source. Birdsong of little cuckoo and gull were used as target and noise signal shown in **Fig. 4(a)**. Delay of arrival were set as $(\tau_1, \tau_2) = (0, 12.5\ \mathrm{ms})$. Sampling frequency was 8000 Hz, and none of filters were used.

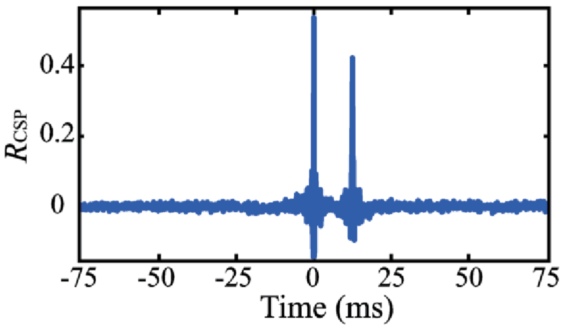

Fig. 3 CSP function : $R_{CSP}(t)$

Result of CSP analysis is shown in **Fig. 3**, this detect τ_1, τ_2 with around $0, 12.5$ ms. Also, result signal we obtained from simulation is shown in **Fig. 4(b)**. Power ratio of signal par noise included in result signal was $\mathrm{SNR}_{\mathrm{pro}} = 37.6$ dB for proposed method, $\mathrm{SNR}_{\mathrm{sum}} = 13.3$ dB for delayed-sum method. And, residual errors of these processes were valuated with comparing with noise signal. The constrained ratio of noise was averagely, -31.2 dB for proposed method, to compare, -8.23 dB for delayed-sum method, respectively. Therefore, proposed method can enhance the target signal with high accuracy.

5. Conclusion

The purpose of this research was to enhance the sound signal from specified direction after estimating DoA. With the method of the geometric method in complex plane based on phase gap estimated from delay of arrival for each frequency, we gained high enhanced ratio compared with delayed-sum method.

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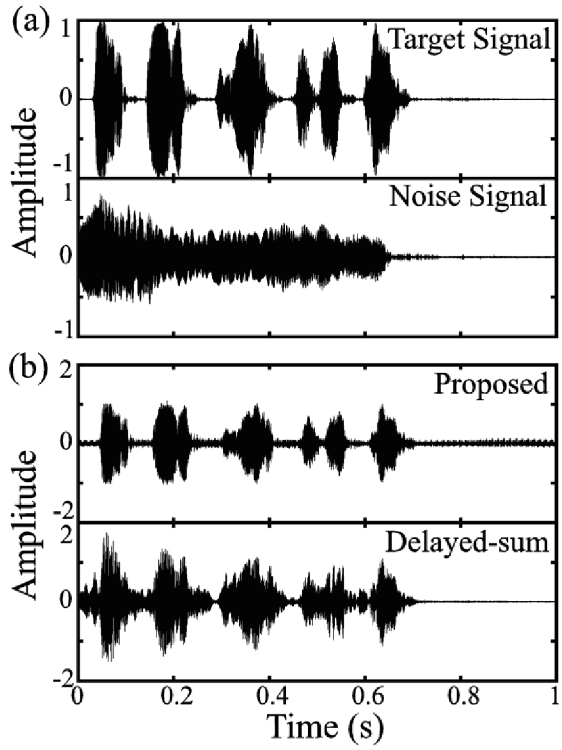

Fig. 4 (a)Input Signals and (b)Results of enhancing the target signal.