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An experimental study on acoustic sensing for occlusion area combining super-directional sound source and super-resolution signal processing

超指向性音源と超解像信号処理を組み合わせた不可視領域センシングの実験的検討

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1. Introduction

Various signals such as sound waves, radio waves, lights, lasers, etc. are used for sensing technology, and sensing systems have been developed takeing advantage of each characteristics.

In this study, we pay attention to diffraction phenomena. The sound wave in the audible range has a relatively long wavelength, and the diffraction effect appears remarkably. We attempted to realize an acoustic sensing system which can detect objects in occlusion area like **Fig. 1**.

2. Proposed method

The effect of diffraction is more pronounced at lower frequencies, and generally the directivity of the emitted sound waves becomes wider at lower frequencies. Therefore, these cause various adverse influence on sensing. The first problem is that the energy of the sound wave diffuses and the Signal-to-Noise Ratios (SNR) become lower, and the detectable distance becomes shorter. The second problem is that unnecessary reflected waves from obstacles generate noises and virtual images. We attempt to solve these problems by using a parametric-speaker which can emit the sound wave with sharp directivity even at low frequencies.

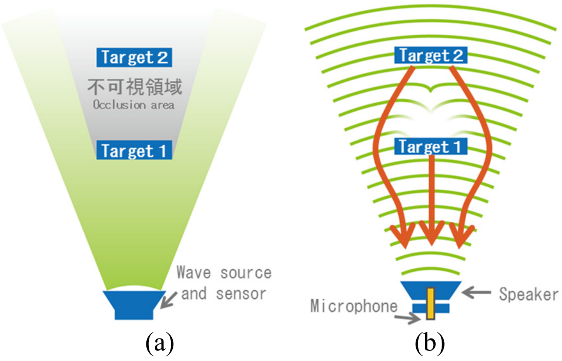
Generally, the use of low-frequency signals performs low-resolution. In addition, it is expected that the SNR of the diffraction wave arriving from the occlusion area is very low. In this study, we introduce the SCM-MUSIC method, a super-resolution signal processing, in order to improve the SNR and resolution.

Fig. 2 shows the features of this study. We propose occlusion area sensing by combining parametric-speaker and SCM-MUSIC method, and experimentally evaluate the feasibility .

3. SCM-MUSIC method

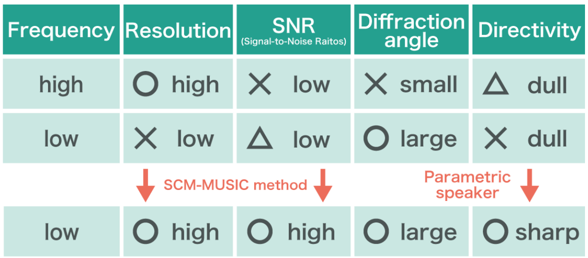
Super resolution FM-Chirp correlation Method - MUltiple SIgnal Classification (SCM-MUSIC) method is combined super-resolution processing MUSIC method with pulse compression technology using FM chirp signal[1].

As a technique to improve the SNR, Pulse Compression Technique (PCT) is often used. With the FM-chirp signal transmitted by applying the PCT, the echo received from a target yields an equivalent effect of transmitting a signal with a high sound pressure.



(a) (b)

Fig. 1 Image of occlusion area sensing.
(a)Straight travelling wave cannot detect target2
(b)Sound wave can detect target2 by diffraction



Frequency	Resolution	SNR (Signal-to-Noise Raitos)	Diffraction angle	Directivity
high	○ high	× low	× small	△ dull
low	× low	△ low	○ large	× dull
	↓ SCM-MUSIC method	↓	Parametric speaker	↓
low	○ high	○ high	○ large	○ sharp

Fig. 2 Features of acoustic sensing in the air.

Althogh the MUSIC method is known as the direction-of-arrival (DOA) estimation method using an array antenna, SCM applies to the delay time estimation. In this method, firstly, while changing the center frequency of the chirp signal by Δf, that of the transmitting signal is changed K times. Each echo signal is received and applied to PCT, and stored in the matrix $z(t)$

$$z(t) = [z_1(t), z_2(t), \ldots, z_K(t)]^{\mathrm{T}} \tag{1}$$

Next, the covariance matrix $\boldsymbol{R}$ is calculated as

$$\boldsymbol{R} = z(t)z(t)^{\mathrm{T}} \tag{2}$$

By solving the general eigenvalue problem defined by the covariance matrix $\boldsymbol{R}$, we can obtain the resultant signals $S(\tau)$ with a resolution higher than that of the original compressed echo signals.

$$\boldsymbol{R}e_i = \lambda_i e_i \quad (i = 1, 2, \ldots, M) \tag{3}$$

$$S(\tau) = \frac{\boldsymbol{u}(\tau)^H \boldsymbol{u}(\tau)}{\sum_{i=D+1}^{M} |\boldsymbol{u}(\tau)^H e_i|^2} \tag{4}$$

where M indicates the sampling points. D indicates the number of reflection waves. e_i indicates the eigenvector. $\boldsymbol{u}(\tau)$ indicates the steering vector.

4. Experiment

Experiments were conducted in the gymnasium of our university. **Fig. 3** shows the experimental environment. The speaker was placed on a speaker stand with a height of 65 cm, and the microphone was set up beneath the speaker. As shown in **Fig. 4**, we prepared wooden boards and human beings as the measurement target. **Table 1** shows the experimental parameters.

Table 2 shows the experimental results. **Fig. 5** show some comparison resutlts of the received (green line), PCT-processed (red dotted line), and super-resolution processed (black line with circle) signals. The left axis shows the sound pressure of the received signal. The right axis shows the relative amplitudes of the PCT- and superresolution-processed signals, which are normalized by maximum values.

In Fig. 5(a), both wooden boards set at d_1= 30 m and d_2= 32 m can be detected. However, when d_2 = 31 m, target 2 in the occlusion area can not be detected. It seems that both targets are too close, diffraction did not affect sufficiently, and the SNR of the reflected waves were reduced.

In Fig. 5(b), both human beings placed at d_1= 5 m and d_2= 7 m can be detected. However, there are many peaks; it may result in virtual images. It seems that the sound waves irregularly reflect toward various directions due to unevenness of human clothes.

5. Conclusion

In this research, in order to realize the occlusion area sensing, we proposed a sensing system combining a parametric speaker and SCM-MUSIC method. As a result of the verification experiment, we confirmed its feasibility.

As a future task, we would like to promote application development that takes advantage of the characteristics of occlusion area sensing and advance this study toward further higher performance.

References

1. T. Wada, K. Okubo, N. Tagawa, Y. Hirose, IEICE, US, 114(464), p.19-22, (2015)

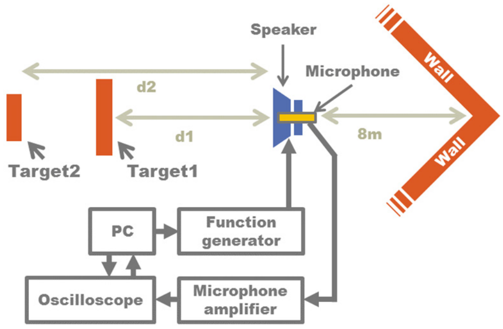
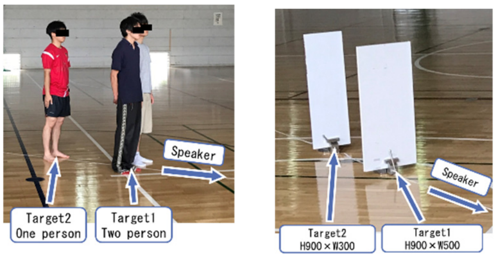


Fig. 3 Experiment environment

Table 1 Experimental parameters

Frequency range of chirp signals,B	1-6kHz
Duration of chirp signals,T	10ms
Step size of frequency,Δf	20Hz
Number of Snapshot,K	31
Cutoff frequency of microphone LPF	10kHz
Sampling frequency	400kHz
Sampling points	100000
Sound speed,c	350.6m/s(32 ℃)



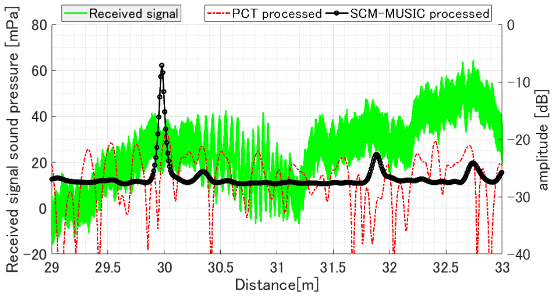
(a) Human beings (b)Wooden boards

Fig. 4 Experimental Target

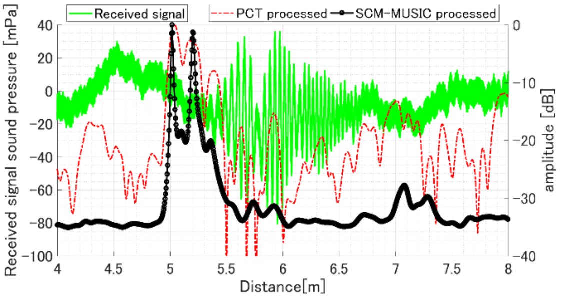
Table 2 Experimental result

Target position		Result	
$d_1[m]$	$d_2[m]$	Wooden boards	Human beings
5	6	◎	○
5	7	◎	◎
15	16	◎	○
15	17	◎	○
30	31	○	×
30	32	◎	×

◎ : Both target were detected
○ : Only target1 was detected
× : Both target were not detected



(a) Wooden boards, d_1= 30m, d_2= 32m



(b) Human beings, d_1= 5m, d_2= 7m

Fig. 5 Comparison of received, PCT-processed, and SCM-MUSIC-processed signals