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Long range acoustic sensing using super-directivity speaker and super-resolution signal processing with pulse compression technique

超指向性スピーカと超解像信号処理を組み合わせた長距離音響センシング

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1. Introduction

With the development of computational technologies, a single processing method becomes important for the ultrasonic and/or acoustic sensing in air.

Generally, in the acoustic sensing, the higher resolution measurement can be enabled as the frequency used is higher. In the long range sensing, however, use of short pulse transmission using high frequencies cannot obtain sufficient SNR signals due to the atmospheric attenuation. That is, the measurable range and measurement resolution are in a trade-off relationship.

Whereas a pulse compression technique (PCT) is used to solve this problem, in our previous studies[1-2], the super-resolution signal processing based sensing technique that combines SCM-MUSIC[3] and PCT have been proposed as a method of ultrasonic measurements in liquid. It discussed the possibility to improve the SN ratio and resolution.

Above mentioned, use of low frequency signals expands the measurable range. However, sound waves of lower frequencies are diffused widely because common speakers are unidirectional and the directivity at lower frequencies are wider. Therefore, it causes the multipath reflection and the unexpected and undesired echoes generate a virtual image. This problem is remarkable in the case of use of lower frequency signals. Therefore, narrow directivity of a speaker is necessary to implement the long range sensing using lower frequency signals.

Frequency	Resolution	Measurable distance	Directivity
high	○ high	× short	△ dull
low	× low	○ long	× dull
	SCM-MUSIC algorithm ↓		Ultra directional speaker ↓
low	○ high	○ long	○ sharp

Fig.1 Features of acoustic sensing in the air.

In this study, we propose high resolution and long range acoustic sensing system combining super-directivity speaker[4] and SCM-MUSIC method with PCT. Figure 1 shows the aspect of this system: The PCT increases SN ratio, the SCM-MUSIC improves the measurement resolution, and the super-directivity speaker realizes the sharp directivity of transmission.

2. Super resolution FM-chirp Correlation Method

The SCM is the super-resolution processing method based on MUSIC[3] like algorithm, and it can be combined with PCT using a FM chirp signal.

As a technique to improve the SN ratio, pulse compression technique (PCT) using a FM chirp signal is often used. Transmitted FM chirp signal, applying PCT the received echo from a target yields equivalent effect as transmitting a signal with high sound pressure. We use a linear chirp signal which sweeps the frequency from low to high frequency; it is expressed

$$u(t) = \sin\{2\pi(f_0 + \frac{B}{2T}t)t\} \quad (-T/2 \le t \le T/2) \quad (1)$$

where T means Duration, B means bandwidth, f_0 means initial frequency. By applying PCT, the SNR is $\sqrt{TB}$ times larger and the measurement resolution becomes inversely proportional to the frequency modulation bandwidth.

SCM is based on MUSIC-like algorithm known as DOA estimation method using an array antenna. The outline of SCM is as follows: The FM-chirp signals with a certain center frequency are transmitted several times. The echo signals are received and the same process is repeated using signals with slight variation of the center frequency. Analytic signals are obtained from the compressed echo signals by applying of an orthogonal detector. Subsequently, the covariance matrix of the above analytic signals is computed. By solving the general eigenvalue problem defined by the covariance matrix, we can obtain the resultant signals with higher resolution than that of the original compressed echo signals.

3. Results and discussion

Figure 2 shows the experiment environment and measurement system; An experiment was made in the gymnasium of our university. Assuming that a target object is at the position of 25m from a super-directivity speaker, and that microphone is set above the speaker.

Figure 3 depicts simulation results; we employ simple modeling of the received signal at the microphone to compute under similar condition. The transmitted signal is multiplied by the Hanning window. The white noise is added to the received signal. Other conditions are shown in Table 1.

Figure 3 provides a comparison of the received signal (black solid line) and super-resolution result (red dotted line). The SN ratio is improved after the super-resolution. It has become extremely narrow with a half width of 9.48mm, which is equivalent to the wavelength of the sine wave of 36.2 kHz.

Figure 4 shows an experimental result. It also compares the received signal of the microphone (black solid line) and super-resolution result (red dotted line). Although clear estimation of the delay time using only the received RF signal is seem to be difficult due to low SN ratio, the proposed method enable us to determine a position of the target object. Here, small peak at about 26 m is expected due to reflection by the back wall of the gymnasium.

5. Conclusion

In this study, we examined the effectiveness of the long range acoustic sensing that combines the super-directivity speaker and super-resolution signal processing with PCT. We show that the proposed method has the possibility to improve the SN ratio and resolution in long range sensing.

Table1 Experimental parameters

Initial frequency f_0	3kHz
Bandwidth B	3kHz
Duration T	10ms
Step size of frequency Δf	10Hz
Snap shot K	31
Sampling frequency	500kHz
Sampling Number	100000
Speed of sound c	343.64m/s(20 ℃)

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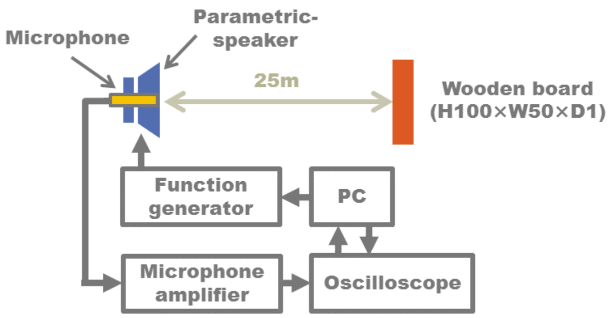

Fig.2 Experiment environment

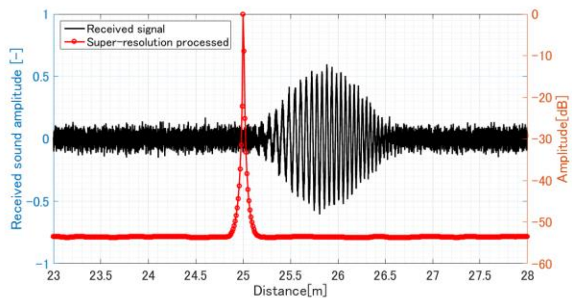

Fig.3 Comparison of signals before and after super-resolution processing (Simulation)

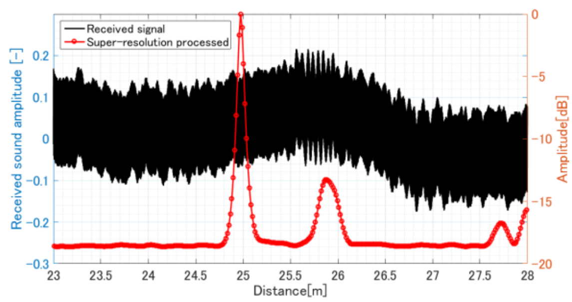

Fig.4 Comparison of signals before and after super-resolution processing (Experiment)