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Investigation on Driving Signal of Sound Source Element in Reflection Point Search by Rectangular Sound Source

矩形音源による反射点探索における音源要素の駆動信号に関する検討

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1. Introduction

Rectangular ultrasonic transducers have four vertices and four sides, and a spatial impulse response of them changes complicatedly depending on the order in which edge waves from these vertices and sides and direct waves from the sound source surface arrive at the observation point[1)]. In addition, the waveform acquired by a rectangular sound source changes depending on the position of the observation point. A method to apply this complicated change to the reflection point search using a single rectangular sound source[2-4)] or a rectangular array sound source with a small number of elements[5-7)] has been proposed.

In this study, a form of the signals for driving the sound source is investigated. To search for the reflection points, the cross-correlation between the acquired reflected signal and the reflected signal obtained by calculations is used. By using the driving signal of the sound source in which the cross-correlation coefficients appear sharply, it is expected that the search results will be improved. The validity of the investigation result is confirmed by performing numerical calculations.

2. Method of Reflection Point Search

The configuration of a rectangular sound source and a reflection point P is shown in **Fig. 1**. The position of the reflection point is indicated by $P(\boldsymbol{r})$. In the calculation result showing in the following section, $\boldsymbol{r}$ is expressed using the distance from the origin of the coordinates ($|\boldsymbol{r}|$), the azimuth angle, and the elevation angle.

When the sound source is driven with uniform velocity $v(t)$, and when the wave radiated from the sound source is reflected at P, the output $e(\boldsymbol{r}, t)$ in terms of the reflected wave received at the sound source is expressed as[8)]

$$e(\boldsymbol{r},t) = -\frac{k\rho A}{2c} v(t) * \frac{\partial}{\partial t} h(\boldsymbol{r},t) * \frac{\partial}{\partial t} h(\boldsymbol{r},t), \quad (1)$$

where k is the proportionality constant, ρ is the density of the propagation medium of the sound wave, A is the area of the region in which the reflection point contributes to the reflection, c is the velocity of sound, $h(\cdot)$ is the spatial impulse response of the sound source, and $*$ denotes the convolution integral.

The procedure diagram for searching for reflection points and obtaining search results is also shown in Fig. 1. Since the rise time of the reflected wave is measurable, the value of $|\boldsymbol{r}|$ can be deter-

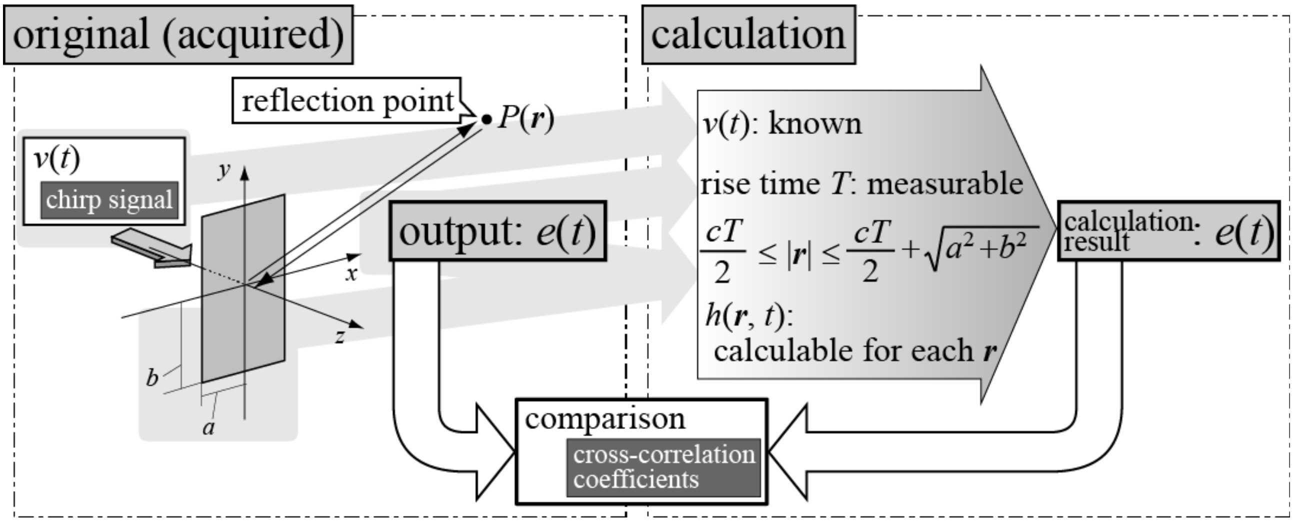

Fig. 1 Configuration of a sound source with a rectangular element and a reflection point P, and the procedure diagram for searching reflection points and obtaining search results.

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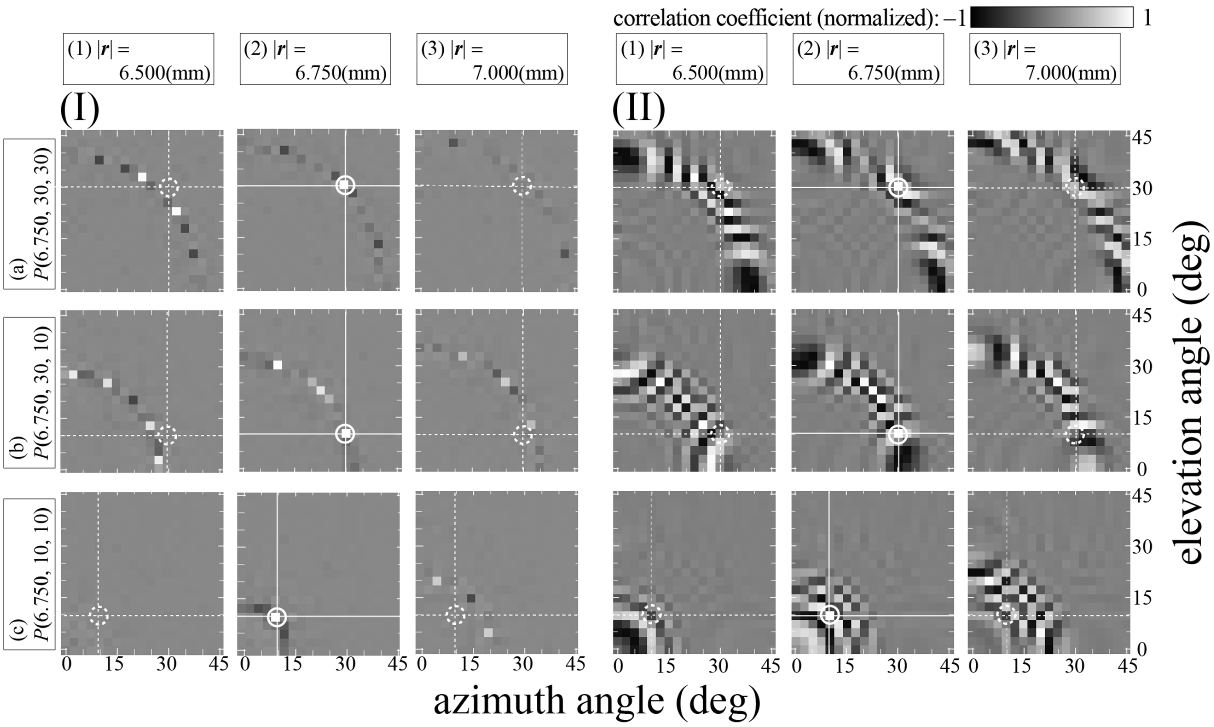

Fig. 2 Calculation results of cross-correlation coefficients using single rectangular sound source at three reflection points: (I) using up-chirp signal for driving sound source; (II) using constant frequency signal for driving sound source.

mined in the range expressed as

$$\frac{cT}{2} \le |\boldsymbol{r}| \le \frac{cT}{2} + \sqrt{a^2 + b^2}, \qquad (2)$$

where T is the rise time of the reflected wave, and c is velocity of sound. When the value of $\boldsymbol{r}$ is set at an appropriate interval in the range of $|\boldsymbol{r}|$, the spatial impulse response $h(\boldsymbol{r}, t)$ corresponding to each $\boldsymbol{r}$ can be obtained. Since $v(t)$ is known, the output waveform $e(\boldsymbol{r}, t)$ in eq. (1) at each $\boldsymbol{r}$ can be calculated. By deducing the cross-correlation coefficient between the waveform obtained by the calculation and the original (acquired) reflected wave in the sequential order, it becomes possible to estimate the position of the reflection point P.

3. Numerical Calculations

The results of numerical calculations by the sound source with a rectangular element are shown in **Fig. 2**. The results are obtained by calculating convolution integral in eq. (1) and the cross-correlation coefficient at time zero with the calculation result for the points around the reflection points sequentially. The dimensions of the sound source used in the calculation are a = 6.450 mm, and b = 10.050 mm. As the driving signal of the sound source $v(t)$, an up-chirp signal whose frequency is increased from 2 MHz to 4 MHz within a duration of 10 cycles is used.

In Fig. 2(I), calculation results of the cross-correlation coefficients for each set reflection point P using the up-chirp signal described above as the driving signal of the sound source are shown. For the comparison, the results of the conventional method using a constant (3MHz) frequency signal as the driving signal of the sound source are also shown in Fig. 2(II). In Fig. 2(I), the obvious striped patterns in Fig. 2 (II) become thinner and almost inconspicuous. Numerical calculation results that are considered to significantly improve the search results can be obtained by chirping the driving signal of the sound source.

4. Summary

Improvement of the reflection point search results using the rectangular sound source was considered by investigating the driving signal of the sound source and introducing the chirp signal. By investigating the form of the driving signal of the sound source and using the signal in which the cross-correlation coefficients required for the reflection point search is expected to appear sharply, significantly improved search results were obtained. It is necessary to further study the method of removing the slight striped patterns that still remain.

References

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