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Reflection Point Search by Rectangular Sound Source with Different Dimensions for Transmitting and Receiving
送受信において寸法が異なる矩形音源による反射点探索

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1. Introduction

Measuring and imaging techniques using ultrasonic waves, a rectangular transducer is widely used as an element of array sound sources. By the effect of four vertices and four sides, the spatial impulse response of the rectangular transducer complicatedly changes in proportion to the position of the observation point of the sound wave[1)]. Therefore, the waveform, which is acquired by driving the sound source, also complicatedly changes with a dependence on the position of the observation point. Utilizing the complicated behavior, and analyzing the waveform of the reflected wave from a point reflector, a method of searching for the position of the reflection point using a single rectangular sound source[2)] or a rectangular array sound source with small number of elements[3)] is proposed. However, when using this method, the failure of the search occurred in the case where the reflection point was located in the position where the direct wave from the sound source arrived.

Here, the technique using a sound source that has the different dimension in transmitting and receiving of sound wave is proposed in order to reduce the effect of the above-mentioned direct wave. Numerical calculations are carried out, and the effectiveness of the proposed technique for the improvement on the search result is examined.

2. Reflection Point Searching Method Using Rectangular Sound Source

As shown in **Fig. 1**, a coordinate system including a rectangular sound source and a point reflector is considered. A sound source, considered as a rectangular transducer array with three elements, is assigned to a plane that is perpendicular to the *z*-axis, so that the center in the central element is the origin of the coordinates. The dimensions of the sound sources are $2a_1 \times 2b$ (for transmitting), and $2a_2 \times 2b$ (for receiving). The position of the reflection point is indicated by $P(\boldsymbol{r})$. When calculation results are shown, $\boldsymbol{r}$ is expressed using the distance from the center of the sound source ($|\boldsymbol{r}|$), the azimuth angle, and the elevation angle, as shown in Fig. 1.

When the wave from the sound source driven

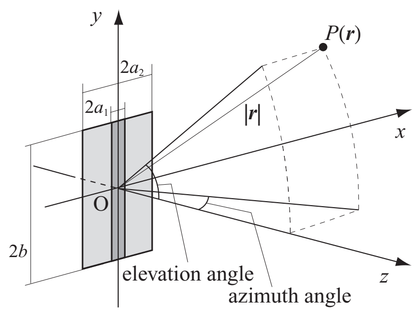

Fig. 1 Geometry of the coordinate system, rectangular sound source and a reflection point *P*.

with uniform velocity $v(t)$ is reflected at the reflection point $P(\boldsymbol{r})$ and returned to the sound source, the output $e(\boldsymbol{r}, t)$ received at the sound source as a result of the reflection at point $P(\boldsymbol{r})$ can be expressed as[4)]

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

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, $h_t(\boldsymbol{r}, t)$ and $h_r(\boldsymbol{r}, t)$ are the spatial impulse response of the transmitting and receiving sound source, and $*$ denotes the convolution integral.

Since the rise time of the reflected wave is measurable, the value of $|\boldsymbol{r}|$ can be determined in a certain range. When the rise time of the reflected wave is T and the velocity of sound is c, the shortest distance between a certain part of the sound source and the reflection point $P(\boldsymbol{r})$ becomes $cT/2$. When $cT/2$ is adopted as the distance from the center of the sound source, $|\boldsymbol{r}|$, the range of $|\boldsymbol{r}|$ using the calculations is given by

$$\frac{cT}{2} \le |r| \le \frac{cT}{2} + \sqrt{a_2^2 + b^2}. \quad (2)$$

When the value of $\boldsymbol{r}$ is set at an appropriate interval in the range of $|\boldsymbol{r}|$, the spatial impulse responses $h_t(\boldsymbol{r}, t)$ and $h_r(\boldsymbol{r}, t)$ corresponding to each $\boldsymbol{r}$ can be obtained. Since $v(t)$ is the known driving signal of the sound source, 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 $\boldsymbol{r}$.

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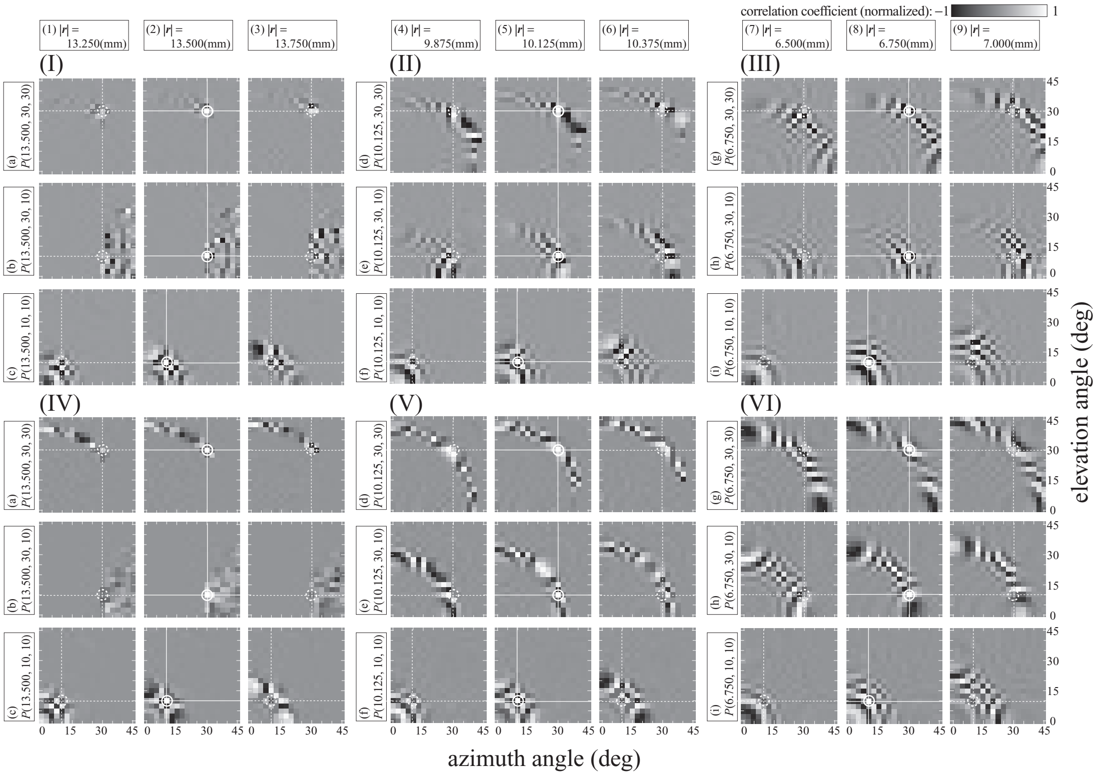

Fig. 2 Calculation results of cross-correlation coefficients at nine reflection points: (I)-(III) using sound source that has different dimension in transmitting and receiving; (IV)-(VI) using single rectangular sound source that has identical dimension for both transmitting and receiving.

3. Numerical Calculations

The results of numerical calculations using the sound source that has the different dimension in transmitting and receiving are shown in **Fig. 2** (Figs. 2(I)-(III)). The results are obtained by calculating $v(t)*(\partial/\partial t)h_t(\boldsymbol{r}, t)*(\partial/\partial t)h_r(\boldsymbol{r}, t)$ in eq. (1) and calculating the cross-correlation coefficient at time zero with the calculation result for the points around the reflection points. The dimensions of the sound sources used in the calculation are a_1 = 0.5 mm, a_2 = 6.45 mm, and b = 10.05 mm. The region of $2a_1{\times}2b$ is used in the transmitting of the sound wave, and the whole region of $2a_2{\times}2b$ is used in the receiving. For the comparison, the results of numerical calculations using a single rectangular sound source of identical dimension of $2a_2{\times}2b$[2] for both transmitting and receiving is also shown in Fig. 2 (Figs. 2(IV)-(VI)).

As a general tendency, the region where a conspicuous fluctuation of the correlation coefficient appears is suppressed, in comparison with the conventional case in which a single rectangular sound source of identical dimension for both transmitting and receiving is used. This tendency appears even in the case in which the reflection point is located for comparatively short distance from the sound source, as shown in Fig. 2(III), and it is considered that this technique is effective for the improvement on the search result in the region where the failure of the search is occurred by the conventional technique. However, as shown in Figs. 2(b)(I) and 2(b)(IV), the case in which the better search result is obtained by the conventional technique also exists.

4. Conclusion

In the reflection point search using rectangular sound sources, the technique using a sound source that has the different dimension in transmitting and receiving of sound wave was proposed, and the effectiveness of the technique for the improvement on the search was examined by numerical calculations.

Calculation results showed that the search result was improved in the many cases, in comparison with the conventional technique with the single rectangular sound source of the identical dimension. However, some search results were not improved in comparison with the conventional technique, and it is necessary to conduct further examinations.

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