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# Improvement on Transmitting and Receiving Technique in Reflection Point Search by Rectangular Sound Source
矩形音源による反射点探索における送受信手法の改善

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## 1. Introduction

Rectangular transducers are widely used in the field of measurement and imaging using ultrasonic waves. The waveform acquired by a rectangular sound source complicatedly changes depending on the position of the observation point, since the spatial impluse response of the rectangular sound source changes in proportion to the position of the observation point[1]. An application of this complicated change to the reflection point search is proposed using a single rectangular sound source[2] or a rectangular array sound source with small number of elements[3,4].

In this study, an improvement from the conventional method is carried out on the dimensions of sound source for transmitting and receiving sound wave. In the sound source used in this study, the dimension of sound source for the transmission of sound wave is set smaller than the conventional methods. Thereby, it aims at the reduction of the failure of the search occurred in the case where the reflection point is located in the position where the direct wave from the sound source arrived, and the improvement on the search result of the position of the reflection point.

## 2. Method of Reflection Point Search

The configuration of a rectangular sound source and a reflection point $P$ is shown in **Fig. 1**. The sound source is assigned to a plane that is perpendicular to the $z$-axis so that the center of the sound source is the origin of the coordinates. The dimensions of the sound source, considered as a rectangular transducer array with two elements, are $2a_1 \times 2b_1$ (for transmitting), and $2a_2 \times 2b_2$ (for receiving). 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 center of the sound source ($|\boldsymbol{r}|$), 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[5]

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

where $k$ is the proportionality constant, $\rho$ 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.

The diagram for searching the reflection

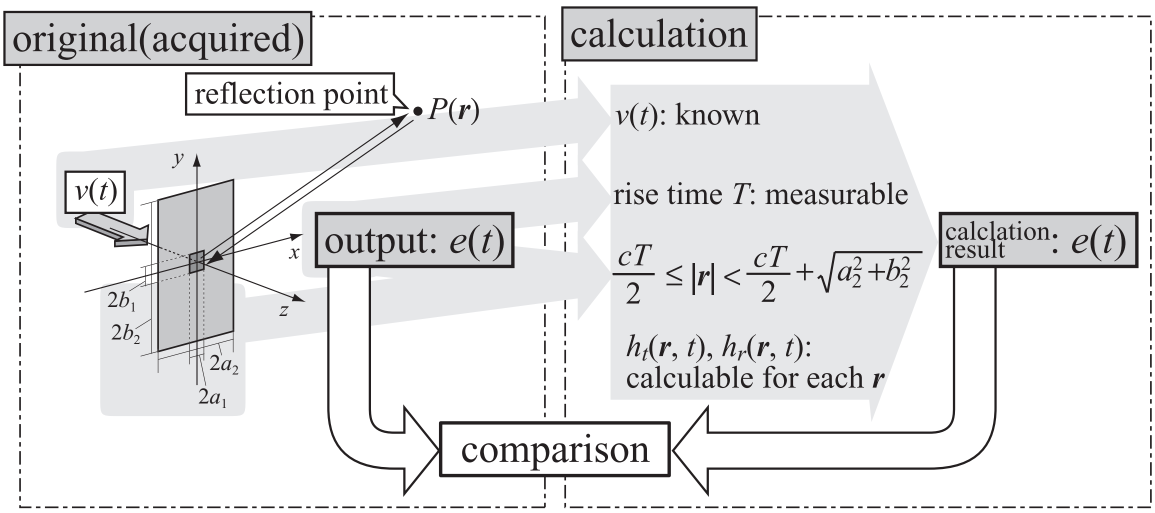


Fig. 1 Configuration of a rectangular sound source and a reflection point $P$, and diagram for searching the reflection point.

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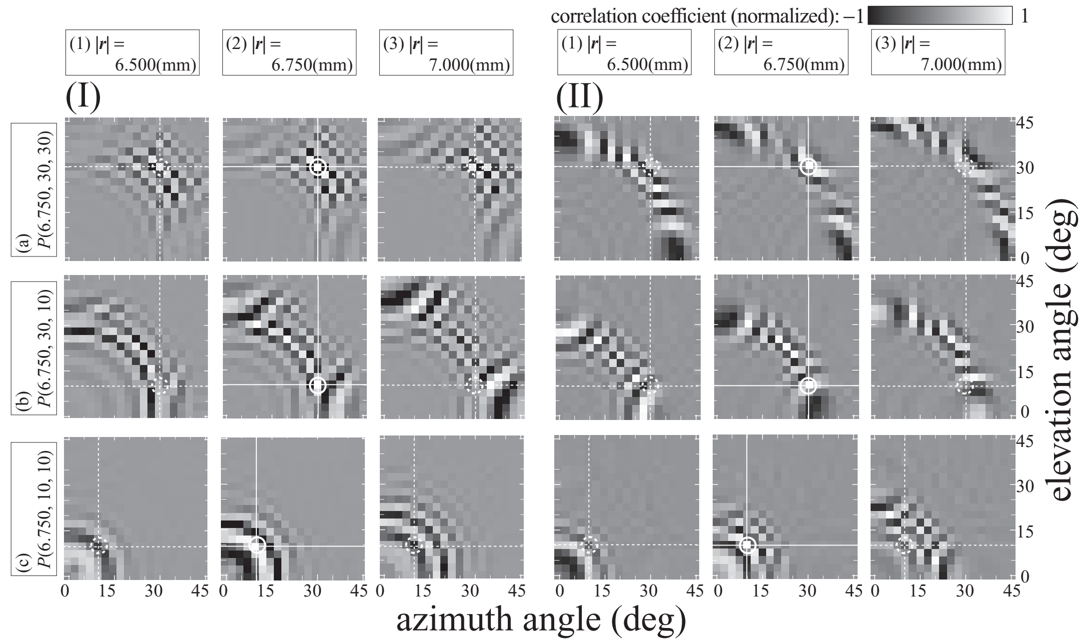


Fig. 2 Calculation results of cross-correlation coefficients at three reflection points: (I) using sound source that has small element for transmitting sound wave; (II) using single rectangular sound source.

point is also shown in Fig. 1. Since the rise time of the reflected wave is measurable, the value of $|\boldsymbol{r}|$ can be determined in the range expressed as

$$\frac{cT}{2} \le |\boldsymbol{r}| \le \frac{cT}{2} + \sqrt{a_2^2 + b_2^2}, \qquad (2)$$

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 responses $h_t(\boldsymbol{r}, t)$ and $h_r(\boldsymbol{r}, t)$ 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 using small element for transmitting sound wave are shown in **Fig. 2**(I). The results are obtained by calculating convolution integral 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 source used in the calculation are $a_1$ = 0.5 mm, $a_2$ = 6.45 mm, $b_1$ = 0.5 mm, and $b_2$ = 10.05 mm. The region of $2a_1 \times 2b_1$ is used in the transmitting of the sound wave, and the region of $2a_2 \times 2b_2$ is used in the receiving. For the comparison, the calculation results by a single rectangular sound source which has the dimension of $2a_2 \times 2b_2$[2)] are also shown in Fig. 2(II).

In comparison with the result using a single rectangular sound source, a conspicuous fluctuation of the correlation coefficient is suppressed, even in the case in which the reflection point is located close to the sound source, as shown in Fig. 2(c). Therefore, it is considered that using proposed sound source gives a certain effect for the improvement on the search result. However, throughout the whole calculation results, the drastic improvement of the search results by the introduction of the proposed sound source is not appeared.

## 4. Summary

In the reflection point search using rectangular sound sources, a sound source that has a small element for the transmittion of the sound wave was introduced, and the effectiveness of this sound source for the improvement on the search was examined. Calculation results showed that the search results were slightly improved by using proposed sound source, compared to the results using single rectangular sound source. However, by the modification of the dimension of the sound source, the drastic improvement of the search result was not achieved, and it is considered that other conditions necessary for the search should be also examined.

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