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Improvement of Reflection Point Search with Rectangular Sound Source by Concise Processing of Search Results

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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[2-5)] or a rectangular array sound source with a small number of elements[6-8)] has been proposed.

In this study, the form of the signal used to drive the sound source is investigated. Cross-correlation between the acquired and calculated reflection signals is used to search for reflection points. By using the source-driven signal in which the cross-correlation coefficient appears sharply, the search result can be expected to be improved. In addition, concise processing is performed on the search result outputs to improve the resulting images. Numerical results are compared to confirm the validity of the processing against the search results.

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[9)]

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

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 determined in the range expressed as

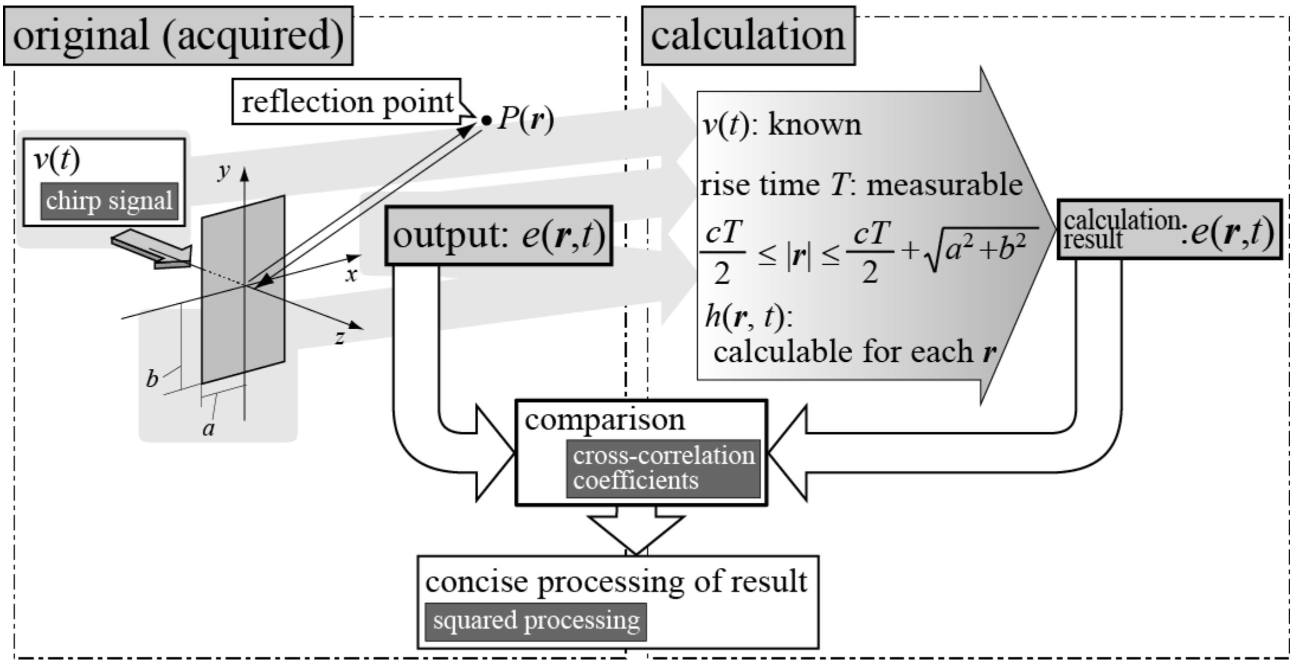

Fig. 1 Configuration of a sound source with a rectangular element and a reflection point P, and the procedure diagram for searching reflection points and obtaining search results.

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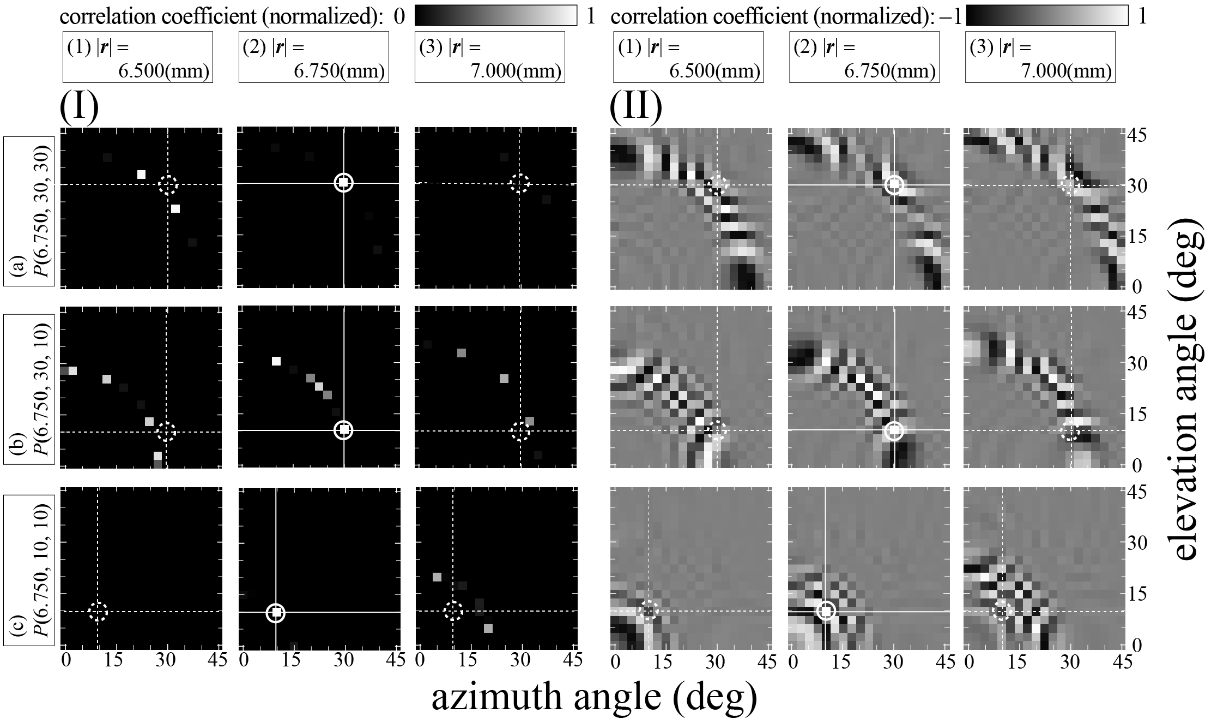

Fig. 2 Calculation results of cross-correlation coefficients using single rectangular sound source at three reflection points: (I) using up-chirp signal and squared processing for search results are applied; (II) using constant frequency signal and squared processing for search results are not applied.

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

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 in which the frequency is increased from 2.5 MHz to 3.5 MHz within a duration of 10 cycles is used.

The up-chirp signal is used as the source driving signal, and the result of squaring the calculated cross-correlation coefficients of the set reflection point P as concise processing in Fig. 1 is shown in Fig. 2(I). For the comparison, the results of the conventional method without squared processing, using a constant (3 MHz) frequency signal as the driving signal for the sound source, are also shown in Fig. 2(II).

In Fig. 2(I), the obvious striped patterns in Fig. 2 (II) become almost inconspicuous. Using a chirp signal as the driving signal of the sound source and applying squared processing to the search results, the outputs are obtained which could be considered to significantly improve the search results.

4. Summary

To improve the results of the search for reflection points using a rectangular sound source, a chirp signal was used as the driving signal for the sound source, and squaring was applied to the output. Numerical results showed a significant improvement over the conventional method. In order to make this method a practical reflection point search method, further simplification of the driving signal and output processing will be necessary.

References

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