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Investigation on Improving Search Results in Reflection Point Search Using Rectangular Sound Source

矩形音源を用いた反射点探索における探索結果の改善法に関する検討

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1. Introduction

Rectangular transducers are widely used as elements of the sound sources for ultrasonic measuring or imaging. They have four vertices and four sides, and a spatial impulse response of a rectangular sound source 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, subject to the spatial impulse response. A method to apply this complicated change to the reflection point search using a single rectangular sound source[2,3] or a rectangular array sound source with a small number of elements[4-11] has been proposed.

In this study, in order to improve the images obtained as search results, a concise processing is performed on the output of search results. Numerical calculation results are compared and the validity of the processing on the results is confirmed.

2. Method of Reflection Point Search

The configuration of a sound source with a rectangular element and a reflection point P is shown in **Fig. 1**. The sound source is assigned to a plane perpendicular to the z-axis, and the center of the sound source is located at the origin of the coordinates. 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[12]

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

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

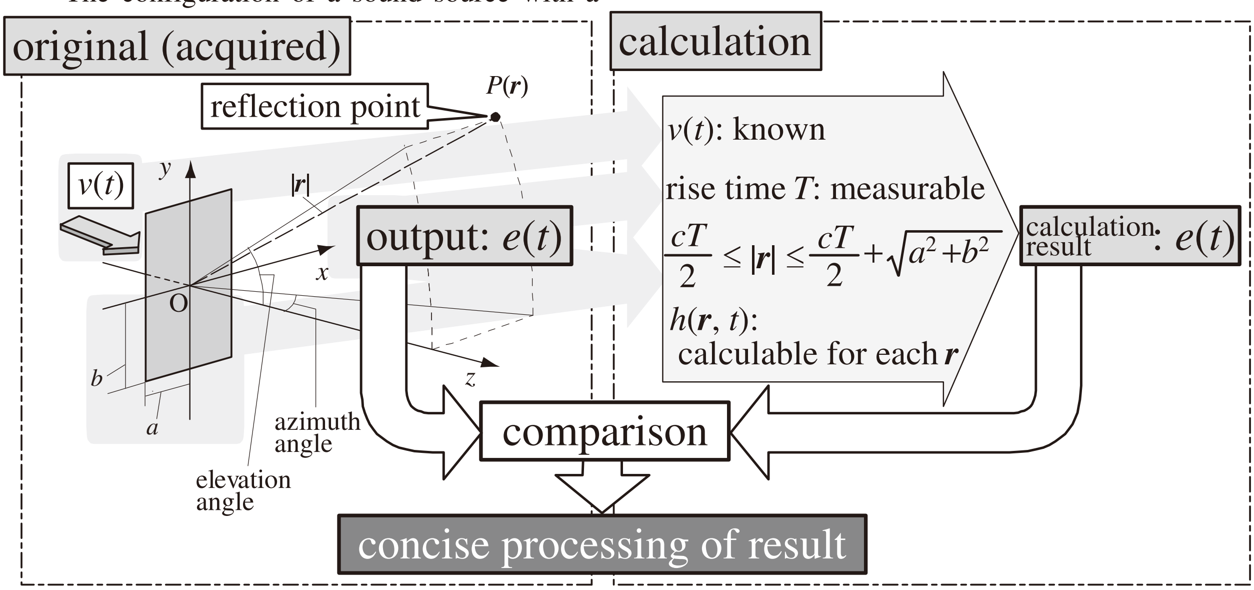

Fig. 1 Configuration of a sound source with a rectangular element and a reflection point P, and the procedure diagram for searching reflection points and obtaining search results.

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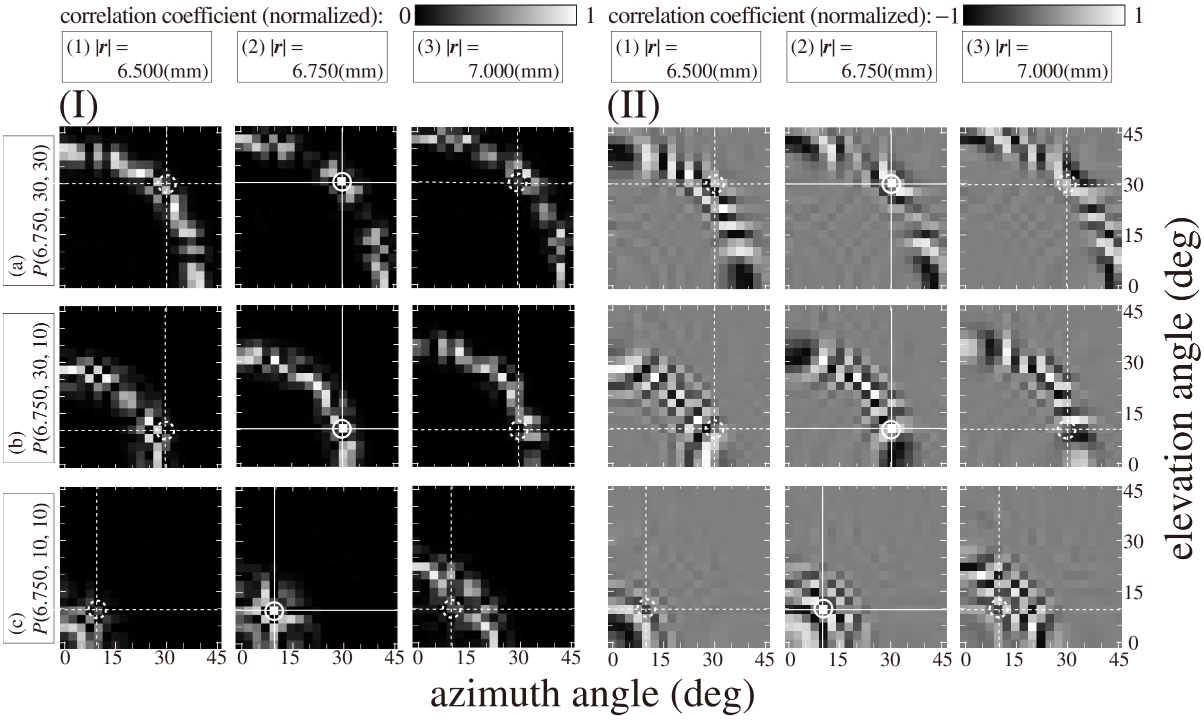

Fig. 2 Calculation results of cross-correlation coefficients using single rectangular sound source at three reflection points: (I) with squared processing for search results; (II) without squared processing for search results.

shown in Fig. 1. Since the rise time of the reflected wave is measurable, the value of |***r***| can be determined in the range expressed as

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

where T is the rise time of the reflected wave, and c is velocity of sound. When the value of ***r*** is set at an appropriate interval in the range of |***r***|, the spatial impulse response $h(\boldsymbol{r}, t)$ corresponding to each ***r*** can be obtained. Since $v(t)$ is known, the output waveform $e(\boldsymbol{r}, t)$ in eq. (1) at each ***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.

In Fig. 2(I), as the concise processing in Fig. 1, the results of squaring the calculation results of the cross-correlation coefficient for each set P is shown. For the comparison, the results of the conventional method without the concise processing are also shown in Fig. 2(II). In Fig. 2(I), the obvious stripe patterns that appear in Fig. 2 (II) are smoothed, and it is considered that improved search results that are easier to recognize than conventional results can be obtained by performing extremely concise processing on the output of the search results.

4. Summary

In order to improve the images obtained as the output of search results in the reflection point search by rectangular sound sources, a squared processing was introduced. The extremely simple method makes it possible to obtain improved search results that are easier to recognize than the conventional results without such processing. Further investigation will be conducted on the arrangement of sound source elements for which this method is more effective.

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