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Numerical Analysis of Time Reversal Process for Target Range Estimation on Ambient Noise Imaging Using Acoustic Lens

周囲雑音イメージングにおける目標距離推定のためのタイムリバーサル処理の数値解析

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1. Introduction

A new method, which views ambient noise as a sound source rather than a hindrance, was developed by Buckingham *et al.* [1] This method, which is neither passive nor active sonar, is called ambient noise imaging (ANI). In our past studies, we analyzed a sound pressure fields focused by an acoustic lens system constructed for an ANI system with a single spherical biconcave lens or a single aplanatic lens using the Finite Difference Time Domain (FDTD) method and the small-scale trials in water tank. Our aim was the development of a lens with a resolution of 1 deg at the frequency of 60 kHz. These results showed that the lens with an aperture diameter of 2.0 m has the sufficient resolution.[2-5]

In ANI system, each pixel of a target image is mapped by either monochrome or pseudo-color to represent its acoustic intensity in each direction. This intensity is obtained by measuring the target object's reflecting or scattering wave, with ocean background noise serving as the sound source. In the case using an acoustic lens, a C-mode image is created by ANI system, where receivers are arranged on a focal plane and each pixel's color corresponds to the intensity of each receiver output. There is no consideration for estimating a target range in this method, because it is impossible to measure a traveling time between a transducer and a target like an active imaging method.

In this study, we applied a time reversal process to estimate a target range on ANI system using an acoustic lens. We calculated the scattering wave from a rigid target object in an acoustic noise field generated by a large number of point sources using the 2-D FDTD method. The scattering wave converged by the lens was then recorded on each receiver (forward propagation). Next, the time-reversed wave of the scattering wave was re-radiated from each receiver position (backward propagation).

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2. Analysis Results and Conclusion

Fig. 1 shows the analysis domain for forward propagation. A spherical rigid target is arranged 10 ± 5 m away from the center of the lens. The angle subtended by the target at the center of the lens is then equal to 1 deg at target range of 10 m. Twelve point sources are arranged to generate a noise field beside the lens. Each point source independently emits Gaussian noise. The frequency band of noise is then limited at 20-90 kHz. The rigid shields and absorption layers are mounted on both sides of the lens, so that the noises from the point sources are not directly within the focusing area. To focus the target at the range of 10 m, 31 receivers are arranged on the image points. Thus, we assume that this imaging system is based on "fixed-focus". The time series of sound pressures on each receiver point is recorded at all time steps of analysis. Fig. 2(a) shows the relative pressure around the lens at forward propagation at the target range of 5 m. In the shield, a peak is formed at $y = -3.5$ m as the scattering waves are converged by the lens. This peak position does not match the receiver positions. The power spectra of the time series of the sound pressure recorded on receivers are shown in Fig. 2(b). We can not visualize the target clearly because the target range does not match the fixed-focused range.

Fig. 3 shows the analysis domain for backward propagation. The point sources are arranged on same positions of receivers in forward propagation. These re-radiate the time-reversed waves of the received signals. Another type of the time-reversed waves, in which the received signals are limited at only high frequency of 60-90 kHz, are also re-radiated. The re-radiated sound pressure distributions on y-axis are shown in Fig. 4. It is suggested to estimate the target range because the maximum position is close to the target position. It is interesting that the time-reversed waves concentrate to the position of target even at the unfocused condition. We can also see that the distribution width has the frequency dependence.

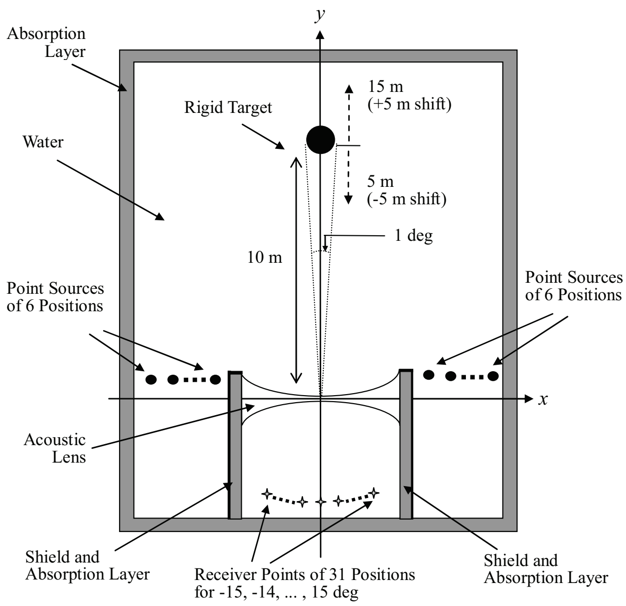


Fig. 1 Analysis domain for forward propagation.

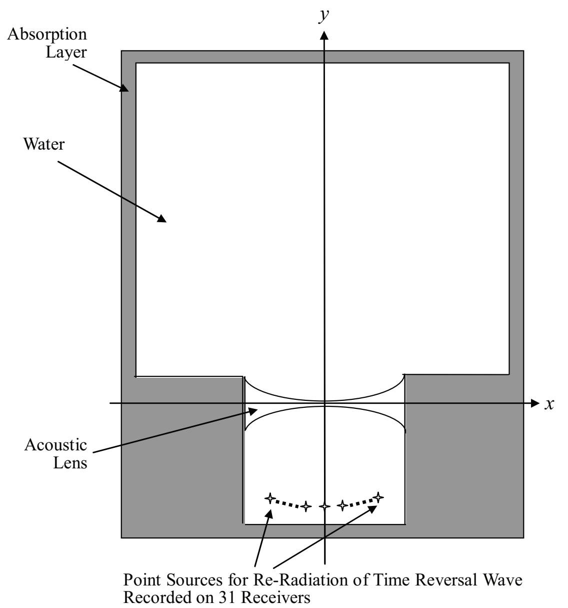
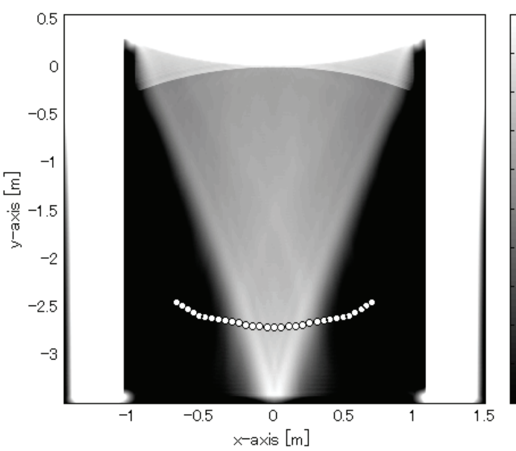
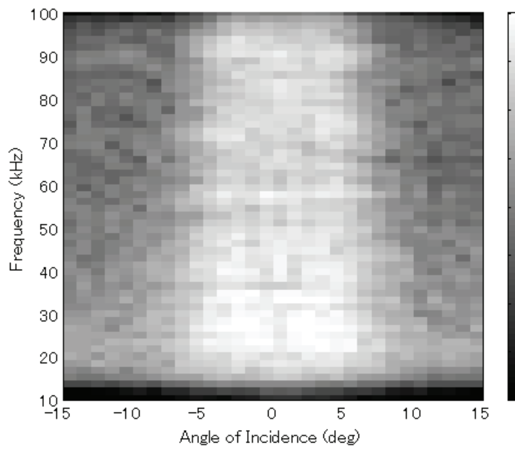


Fig. 3 Analysis domain for backward propagation.



(a)



(b)

Fig. 2 Analysis results of forward propagation. The relative sound pressure fields of scattering wave from target at 5 m range are shown in (a). Here, the positions of 31 receivers are represented with the circle marks. The power spectrum of the received signals at image points are shown in (b).

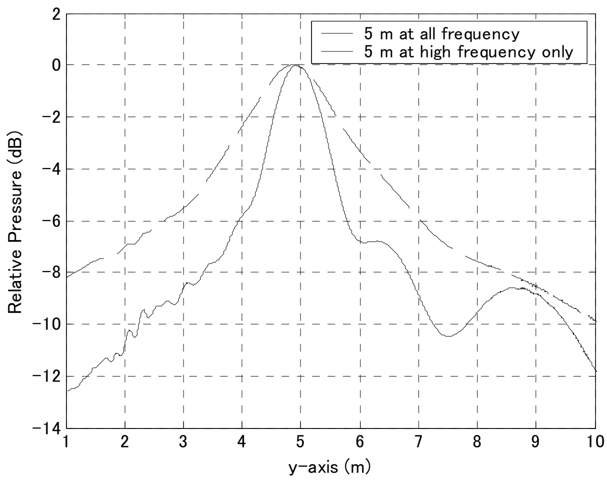


Fig. 4 Comparison of relative pressure distribution on y-axis through maximum point for backward propagation.

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