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A Basic Study for Target Range Estimation on the 2010 Sea Trial of Ambient Noise Imaging with Acoustic Lens
音響レンズによる周囲雑音イメージングの実海域試験における目標距離推定の基礎研究

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1. Introduction

Buckingham *et al.* developed a revolutionary idea, which views ambient noise as a sound source rather than a hindrance, and which is neither a passive nor an active sonar. [1] This method is often called ambient noise imaging (ANI), and an acoustic lens system would be a suitable choice for realizing ANI, because such a system would not require a large receiver array and a complex signal processing unit for two-dimensional beam forming, which could reduce the size and cost of the system. In our past studies, we analyzed a sound pressure field focused by an acoustic lens constructed for an ANI system with a single spherical biconcave lens or a single aplanatic lens. [2-4] We already designed and made an aspherical lens with an aperture diameter of 1.0 m for ANI. It was verified that this acoustic lens realizes directional resolution, which is a beam width of 1° at the center frequency of 120 kHz over the field of view from -7 to +7°. [5] And, the silent target was successfully detected under only ocean natural ambient noise, which is mainly generated by snapping shrimps on the 2010 sea trial conducted at Uchiura Bay. [6] Recently, we estimated the spatial distribution of noise sources using a pair of tetrahedron arrays, and some results and discussions of relationship between noise source positions and target scatterings were reported. [7]

In this study, we are trying to estimate a target range using the transients of target scatterings detected in the 2010 sea trial. We already proposed a method of target range estimation in ANI with an acoustic lens using a numerical simulation of sound propagation based on the principle of the time-reversal mirror. [8] **Figure 1** shows our approach. In the forward propagation, the scattering waves from the target are generated by the natural ambient noise sources and are converged by the lens. The receivers on the focal plane then record the converged scattering waves. In the backward propagation, the time-reversed waves derived from the received waves are reradiated from all receiver positions. We can assume that the maximum position of the refocused sound pressure distribution matches the target position when the media including the water and lens maintain reciprocity between the forward and backward propagations.

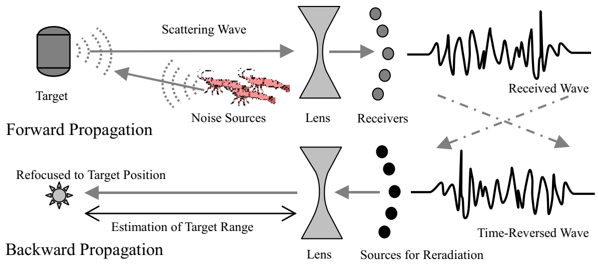

Fig. 1　Approach for target range estimation using ANI system with acoustic lens.

2. Experimental Setup and Example of Target Scattering

The equipment was deployed through the barge "OKI SEATEC II", which was moored at Uchiura Bay. The water depth at this location is a nominal 30 m. The experimental setup conducted on November of 2010 is shown in **Fig. 2**. The prototype imaging system constructed with the acoustic lens and hydrophone array were suspended from the end of the barge. The aluminum panels of Target A and B were also suspended. The distance between the lens and each target was about 30 and 15 m, respectively.

The trial of silent target detection using only ocean natural ambient noise was conducted. An example of transient of target scattering is shown in **Fig. 3**. We can see the transient pulse in the look directions around 0° in Fig. 3. As in this example, many transients of target scatterings were received by the hydrophones corresponding to the on-target direction through the lens. Therefore, it can be expected to estimate the target range by reradiating the time-reversed waves of these target scatterings.

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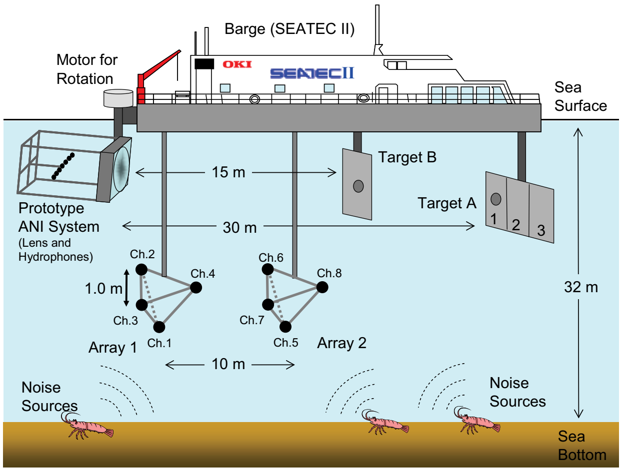

Fig. 2 Experimental setup in the 2010 sea trial.

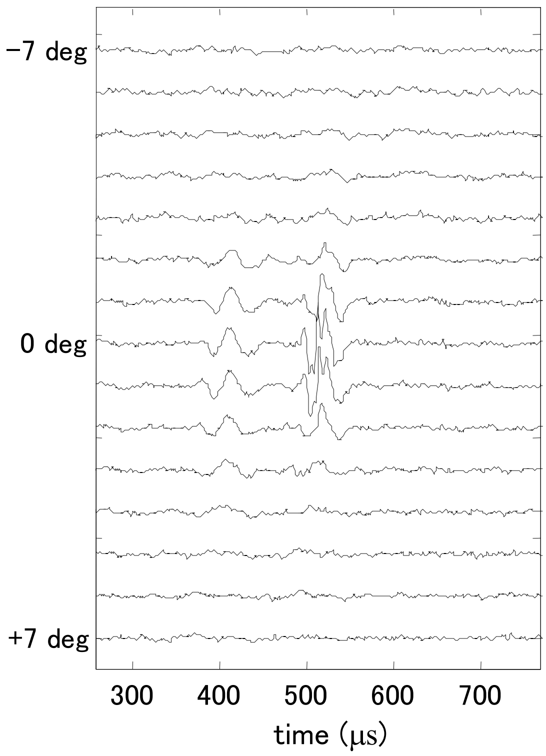

Fig. 3 Example of transient sound of target scattering detected in the 2010 sea trial.

3. Numerical Calculation Method for Backward Propagation

It is necessary to reradiate the time-reversed wave of target scattering in the backward propagation using numerical calculation. We require a numerical calculation for a full three dimensional (3D) wave propagation model. **Figure 4** shows the 3D volume of analysis domain using hybrid calculation of Parabolic Equation (PE) method and Finite Difference Time Domain (FDTD) method. We had analyzed sound fields focused by acoustic lenses using the 3D FDTD method.[3, 4, 9] The FDTD method realized a high accurate calculation, but it requires large memory size. It is difficult to analyze a sound field for a long range propagation using only the FDTD method. Here, we propose to analyze the sound field of the long range propagation after passing through the lens using the Parabolic Equation (PE) method, because it realizes a fast calculation with small memory size. We are now developing the FDTD-PE hybrid code. In the near future, it will be able to estimate the target ranges by applying the time reversed-waves of the target scatterings detected in the 2010 sea trial.

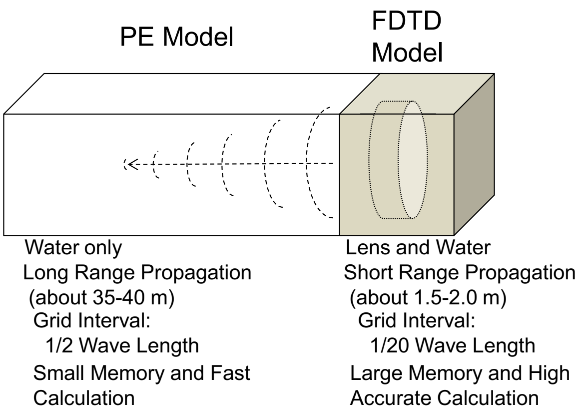

Fig. 4 3D volume of analysis domain of numerical calculation for backward propagation.

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