PRELIMINARY DATA ANALYSIS OF THE 3RD SEA TRIAL FOR AMBIENT NOISE IMAGING WITH ACOUSTIC LENS

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Abstract: *We previously designed and produced a prototype system with an aspherical lens that had a 1-m aperture diameter and a 2-D receiver array with 127 elements for ambient noise imaging (ANI). We verified that this system could realize the directional resolution, which is the beam width of 1 degree at the centre frequency of 120 kHz, a horizontal field of view of 15 degrees, and vertical of 9 degrees. In November 2014, a 2nd sea trial was conducted to evaluate the performance of this ANI system. The detected images mapping intensities of target scatterings successfully expressed the shapes of some silent targets, consisting of panels and spheres under natural ocean ambient noise, generated mainly by snapping shrimps. In the present study, we attempted to detect images of silent targets with frequency-dependent echoes generated by snapping shrimp noises. The 3rd sea trial was conducted to detect two sphere targets in November 2016 in Uchiura Bay. Each target was designed to have a frequency response peak of 80 or 160 kHz. Our ANI system successfully received the different frequency-dependent echoes from the two targets. In the near future, we plan to create target images from received echos to express target frequency dependence with RGB additive colour mixing. Here, the received frequency band from 50 to 200 kHz will be divided into three parts, and the received intensities of low-, mid-, and high-frequency bands will be assigned to Red, Green, and Blue colour, respectively.*

Keywords: *Ambient noise imaging, Acoustic lens, Sea trial, frequency dependent echo*

1. INTRODUCTION

Buckingham *et al.* first developed the revolutionary idea of viewing ambient noise as a sound source rather than as a hindrance [1]. This method of sonar, that is neither passive nor active, is often called ambient noise imaging (ANI). Several groups have built experimental systems to verify the idea of ANI. Epifanio *et al.* developed the Acoustic Daylight Ocean Noise Imaging System (ADONIS) consisting of a 3-m-diameter spherical reflector with an array of 126 hydrophones attached to the focal surface [2]. Venugopalan *et al.* built the Remotely Operated Mobile Ambient Noise Imaging System (ROMANIS) consisting of a 2-D sparse array of 504 hydrophones fully populating a 1.44-m circular aperture [3]. These systems were able to successfully detect silent target objects under dominant snapping shrimp noises. Recently, the ROMANIS was rebuilt by Chitre *et al.*, who were also able to create stable target images. At the same time, they successfully estimated the target range using noise source positions [4].

In our previous studies, we analysed several sound pressure fields focused by lenses constructed for an ANI system [5-7]. We also designed and built an aspherical lens with an aperture diameter of 1.0 m for our 1st prototype ANI system. On November 8-13, 2010, the 1st sea trial of our 1st prototype ANI system was conducted by mounting a 1-D hydrophone array on the image surface of the lens to measure its directional resolution. We verified that this acoustic lens achieved directional resolution with a beam width of 1 degree at the centre frequency of 120 kHz over a field of view from −7 to +7 degrees [8].

Another silent target detection sea trial was also conducted under only background noise in Uchiura Bay, Japan. Many transient sounds were detected by hydrophones arranged on each image point. We classified the received transients roughly into directly received noises and target scatterings. A classification method was proposed to extract only transients classified as target scatterings. Finally, we were able to verify that the power spectrum density levels of the on-target directions were greater than those of the off-target directions in the frequency band higher than 60 kHz using the data classified as target scatterings. Thus, we succeeded in detecting silent targets under ocean background noise generated mainly by snapping shrimp [9].

Recently, we estimated the spatial distribution of noise sources using a pair of tetrahedron arrays, and reported some results along with a discussion of the relationship between noise source positions and target scatterings [10]. To create a pictorial image of a target under natural ocean ambient noise, it is necessary to arrange a 2-D hydrophone array to provide full coverage of the image surface. We therefore built our 2nd prototype ANI system with a 2-D hydrophone array. To evaluate the 2nd prototype system, a 2nd sea trial was conducted in Uchiura Bay in November 2014. The data analysis results showed that the pictorial images of some targets were successfully created using ambient noise [11, 12].

In the present study, we tried to image silent targets with frequency-dependent echoes generated by snapping shrimp noises. The 3rd sea trial was conducted to detect two sphere targets in November 2016 in Uchiura Bay. Targets were designed to have a frequency response peak of 80 kHz or 160 kHz. In this paper, we report the preliminary results of the analysis.

2. EXPERIMENTAL SETUPS

The 3rd sea trial was conducted in an actual ocean environment on November 28-30, 2016. As in the 1st and 2nd sea trials, the equipment was deployed on the barge "OKI SEATEC II", which is moored at Uchiura Bay. The water depth at this location is a nominal 30 m. The experimental arrangement is shown in Fig. 1. The 2nd prototype imaging system constructed with the acoustic lens and hydrophone array was suspended from the end of the barge. To eliminate the directly received noises, the soundproof boards were attached around the hydrophone array. Two sphere targets, called SonarBells® (SALT Ltd.), were suspended from the barge. The SonarBell is a kind of passive sonar reflector, and can be designed beforehand to have a frequency response for single or multiple peaks, or for a broadband response [13]. In this trial, we designated the frequency response of each target to have a single peak of 80 kHz or 160 kHz, and each diameter was 275 mm. Two pingers, which are spherical sound sources 22 mm in diameter, were also attached near the targets for verification of ANI detection and target alignment; these radiated burst pulses of 130 kHz. Using a spherical element made of piezoelectric ceramics, the pinger had nearly perfect omni-directionality in the horizontal and vertical directions. At the beginning of the trial, we confirmed that the targets were present in the field of view using the pingers' sound. The frequency-dependent echoes were collected under natural ambient noise generated by snapping shrimps, after pinger radiations were silenced.

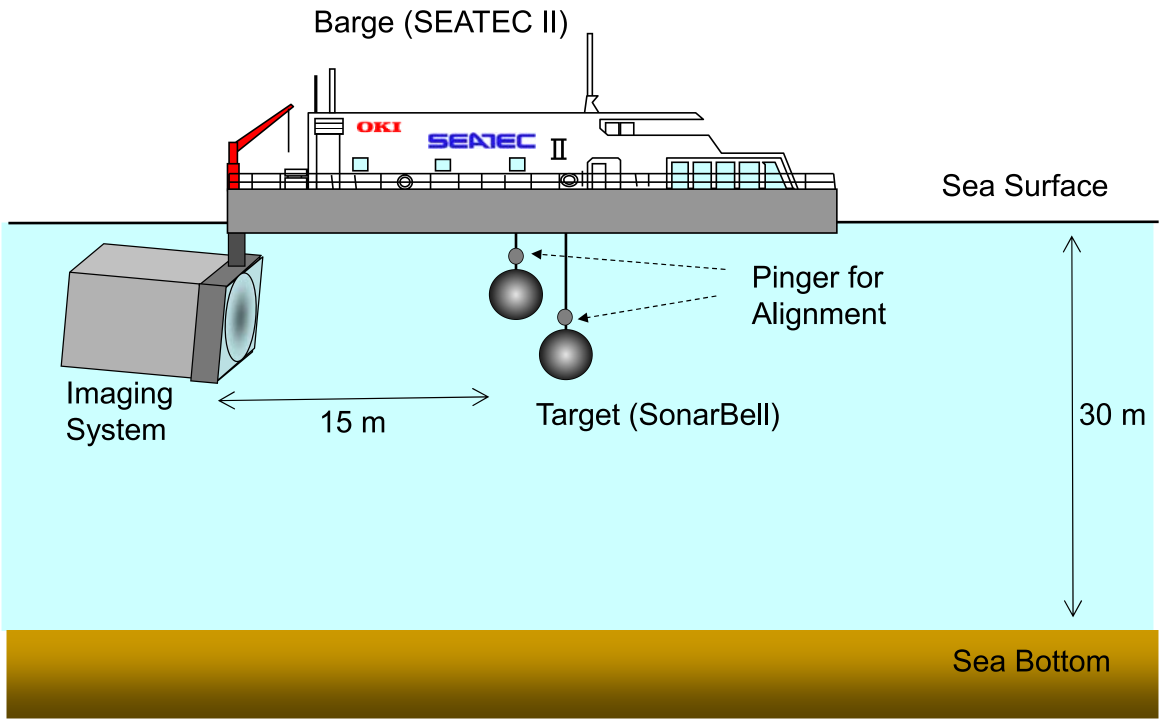

Fig.1: Experimental arrangement of the 3rd sea trial.

3. PRELIMINARY DATA ANALYSIS RESULTS

Figure 2 shows the preliminary data analysis results in the 3rd sea trial. The figure contains examples of time series of target echoes, its power spectrum, and spectrum's difference between on-target and off-target. In Fig. 2(a), echoes from the 80-kHz target were detected by the received beam for the horizontal angle of +1 degree and the vertical angle of 0 degree. The SonarBell generates echoes composed of two components. We can see that the time series includes a 1st echo at about 600 μs and a 2nd echo at about 1600 μs. The former is scattered from the front face of the target, and the latter is focused and back in the direction of the sound source by the inner structure of the SonarBell [13]. The power spectra at on-target and off-target show the different shapes around 80 kHz, and the difference in the spectra shows that the echoes have a frequency response peak of 80 kHz. In Fig. 2(b), for the 160-kHz target, similar echoes were detected by the received beam for the horizontal angle of +6 degrees and the vertical angle of 0 degree. It can be seen that the time series includes a 1st echo at about 500 μs and a 2nd echo at about 1500 μs. The power spectra at on-target and off-target show the different shapes around 160 kHz, and the difference in the spectra shows that the echoes have a frequency response peak of 160 kHz. Thus, it was confirmed that our ANI system can receive different frequency-dependent echoes from two targets.

4. CONCLUSIONS

In this study, we tried to image silent targets with frequency-dependent echoes generated by snapping shrimp noises. The 3rd sea trial was conducted to detect two sphere targets called SonarBells in November 2016 in Uchiura Bay. Targets were differentially designed to have a frequency response peak of 80 kHz or 160 kHz. Our 2nd prototype ANI system successfully received the different frequency-dependent echoes from the two targets.

In the near future, we plan to create the target image by these received echoes to express target frequency dependence with RGB additive colour mixing. Here, the received frequency band from 50 to 200 kHz will be divided into three parts, and the received intensities of the low-, mid-, and high-frequency bands will be assigned to Red, Green, and Blue colour, respectively. Then, the each pixel of the image will provide information not only regarding the intensity, but also the principal frequency of the target echo.

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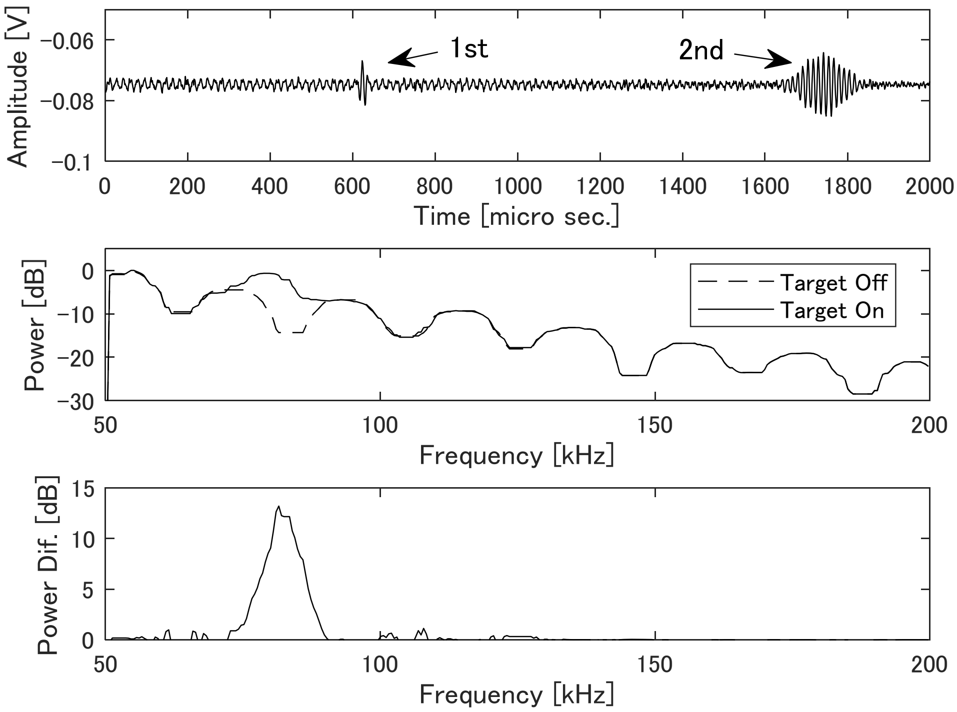
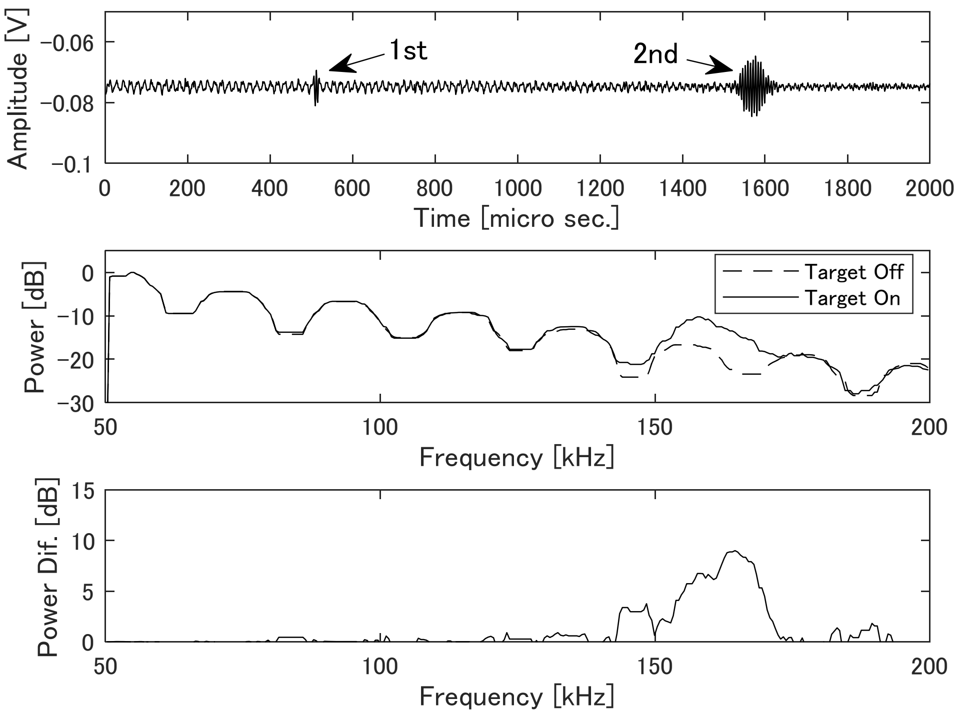


(a) Target of 80 kHz



(b) Target of 160 kHz

Fig. 2: Example of time series of target echo (top panel), its power spectrum (mid panel, solid line: on-target; broken line: off-target), and spectrum's difference between on-target and off-target (lower panel) obtained in the 3rd sea trial. (a) Results of 80-kHz target; (b) results of 160-kHz target.

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