3J1-5

Underwater acoustic positioning in reflective environments using acoustic lens and code division multiplexing

Yuji Sato[†], Tadashi Ebihara[*], and Naoto Wakatsuki
(Univ. Tsukuba)

1. Introduction

Recently, the cooperative use of multiple underwater vehicles has attracted attention for more efficient ocean exploration[1]. Underwater acoustic (UWA) communication is one of the techniques to establish underwater mobile network. However, the establishment of an UWA network is still challenging, since the collision of packets on a shared single channel can result in performance degradation. Thus, multiple access techniques (*e.g.*, time-, frequency-, code- or space-division multiplexing) or packet scheduling algorithms have been considered[1].

As an alternative, we have proposed a space-division multiplexing UWA communication system using a wide-angle acoustic lens. The use of lens has the potential to realize a simple UWA network because it can transmit and receive multiple beams simultaneously without the need for complicated processing. Furthermore, by aiming at the communication partner using the lens's beam-forming effect, there is also the advantage of being able to suppress reflections from the sea surface and the sea bottom.

In order to accurately aim the communication pertners it is nesessary to know their position in detail. When using a communication device with a lens to perform simultaneous positioning, it was possible to estimate direction with a resolution of 1° when a lens with a resolution of 10° was used[2]. However, if the perter's position is not known, it will be nesessary to use a non-directional pinger to determine the location, and this will be greatly affected by reflections. Therefore, we propose a probe sound that transmits different codes for each direction from the transmitter simultaneously in order to enable accurate positioning even under the influence of reflections.

In this paper, we attempt to achieve accurate positioning in a reflective environment by transmitting 18 Gold sequences simultaneously over a 180° range and separating the direct sound from the reflected sound. We show the transmission and the transmission-reception characteristics in a non-reflective environment using the 2-dimensional finite difference time domain (2-D FDTD) method. We also perform several simulations in a reflective environment to clarify the feasibility of positioning.

E-mail: [†]yuji@aclab.esys.tsukuba.ac.jp,
[*]ebihara@iit.tsukuba.ac.jp

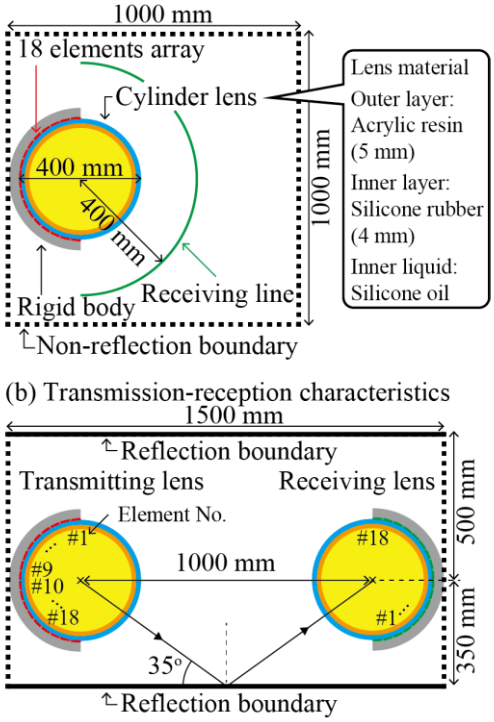

Fig. 1 Schematic view of simulation: (a) Beam pattern and (b) Transmittion-reception characteristics.

Table I Parameters of media

	Velocity (m/s)	Density (kg/m³)	Attenuation (Np/m)
Water	1500	1000	0
Acrylic resin	2700	1140	1.36
Silicone rubber	700	2250	4.32
Silicone oil	1000	760	0

2. Simulation conditions

The lens system and the simulation fields are shown in **Fig. 1**. The cylindrical lens was designed using acrylic resin, silicone rubber with metal powder, and silicone oil. Their parameters are shown in **Table I**. The diameter of lens is 400 mm. A 18-element transmit-receive array is installed on the back of the lens, and a rigid backing material is used. The elements of the array are numbered as shown in Fig. 1(b). Each element emits different BPSK modulated signal using a 127-digit Gold sequence, which center frequency is 40 kHz and bandwidth is 40 kHz.

The simulation field is 1000 mm square per side when the beam pattern is calculated as shown in Fig. 1(a). The simulation field is discretized by 1 mm, and filled by water. The boundaries are Higdon's 2nd

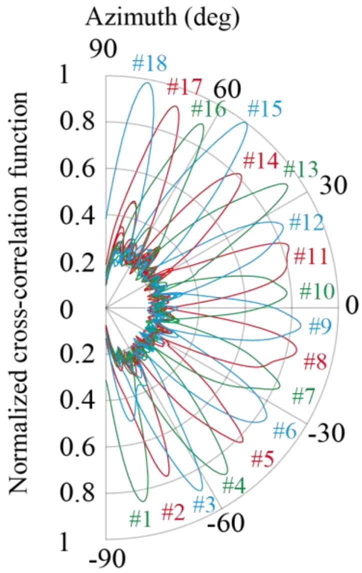

Fig. 3 Simulated beam pattern.

order non-reflection boundary. The cylindrical lens is arranged in the left side of the calculation field. The sound pressure waveform at a distance of 400 mm from the center of the lens is aquired. The sampling frequency for the simulation is 8 MHz. The cross-correlation function is calculated for the received signal at each receiving position and the 18 types of transmitted signals, and the characteristics are evaluated using the maximum value of the absolute cross-correlation functions.

The simulation field is 1000 mm by 1500 mm when the transmission-reception characteristics are calculated as shown in Fig. 1(b). The transmitting lens and receiving lens are facing each other. The distance between the centers of the two lenses is 1000 mm. The top and bottom boundaries are reflective and assumed to be reflective surfaces corresponding to the sea surface and seabed, respectively. The sound pressure waveform on the receiving array is acquired by space integration of sound pressure in front of each element. The cross-correlation function is calculated and used for evaluation in the same way as described above.

3. Results of simulation

The calculated beam pattern is shown in **Fig. 2**. The azimuth angle is defined as -90° in the frontal direction of element #1 and 90° in the frontal direction of element #18. The beam pattern is normalized by the maximum value of the beam from element #15. The beams appear at equal intervals. The angle from the peak of the element #1 to the peak of the element #18 is about 160°. Although it does not reach a 180° angle of view, it is still a wide-angle lens. The shape of the beam changes depending on the element. The beam of the element #2 is the smallest, with a maximum value of 0.77. It is a future issue to be able to select the appropriate

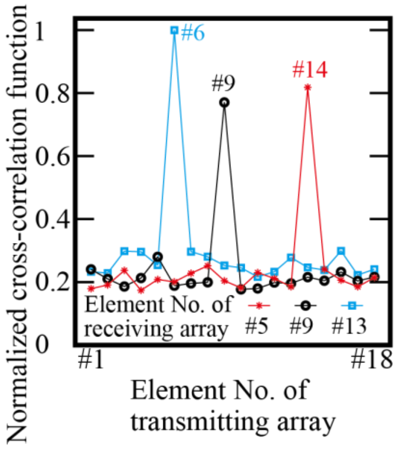

Fig. 4 Cross-correlation functions between receiving element #5, #9, and #14 and transmitting elements.

Gold sequences, which shows almost same beam patterns.

The maximum absolute value of the cross-correlation function between the received signals at the receiving elements #5, #9 and #13 and the 18 transmitted signals is shown in **Fig. 3**. The vertical axis is normalized by the maximum value of the receiving element #13. The horizontal axis shows the element number of the transmitting array. The receiving element #5, indicated in red line, shows the highest correlation with the transmitting element #14. This means that sound waves transmitted at 45° are reflected at the top boundary and received. The receiving element #13 the transmitting element #6 shows the reflection at the bottom boundary. The receiving element #9 shows a high correlation with transmitting element #9. This means that the sound waves transmitted at -5° were received directly. Therefore, it was possible to separate the direct sound wave and the reflected sound wave.

4. Conclusion

Using Gold sequences and the wide-angle acoustic lens, we confirmed through simulation that it is possible to separate direct sound waves and reflected sound waves in a reflective environment. Therefore, it is thought that there is a possibility that the proposed method can also be applied in reflective environments. We plan to continue our research into complex reflective boundaries and wide-area positioning.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 23H01617.

References

1) E. M. Sozar, M. Stojanovic, and J. G. Proakis, IEEE J. Ocean. Eng. **25**, 72 (2000).
2) Y. Sato T. Ebihara, N. Urasaki, K. Mizutani, and N. Wakatsuki, Jpn. J. Appl. Phys. **63** 05SP07 (2024).