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Investigation on underwater acoustic positioning using wide-angle acoustic lens

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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.

As an alternative, we have proposed a space-division multiplexing UWA communication system using a wide-angle acoustic lens[2, 3]. 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. Additionally, aiming at the communication partner with the beam forming effect of the lens prevents delay spread.

In order to aim at the communication pertner, it is necessary to know the pertner's position. Generally, existing UWA positioning can be classified into three types: long baseline (LBL), short baseline (SBL) and super-short baseline (SSBL) methods[4]. These methods use the time of flight (ToF) or phase difference to obtain pertner's direction and distanse. We propose a new positioning method using UWA lens which can obtain the direction by the beam forming effect.

In this paper, we invetigate fundamental property of UWA positioning using a wide-angle lens. The lens is cylindrical acrylic resin filled with hydrofluoroether (HFE). Focused pressure fields and received signals are calculated by 2-dimensional finite difference time domain (2-D FDTD) method.

2. 2-D FDTD Simulation

The lens and the calculation field are shown in **Fig. 1**. The calculation field is 500 mm square per side, discretized by 1 mm, and filled by water. The cylindrical lens made of acrylic resin is arranged in the center of the calculation field. The lens diameter is 400 mm and its thickness is 5 mm. The lens is filled by HFE. A line source is arranged on z = -245 mm and emits a chirp signal (center frequency: 37.5 kHz and bandwidth: 5 kHz). The lens is rotated to change the angle of incidence θ. Parameters of each mediums are shown in **Table I**. The sampling frequency for the simulation is 8 MHz. The calculation time is 3.75 ms.

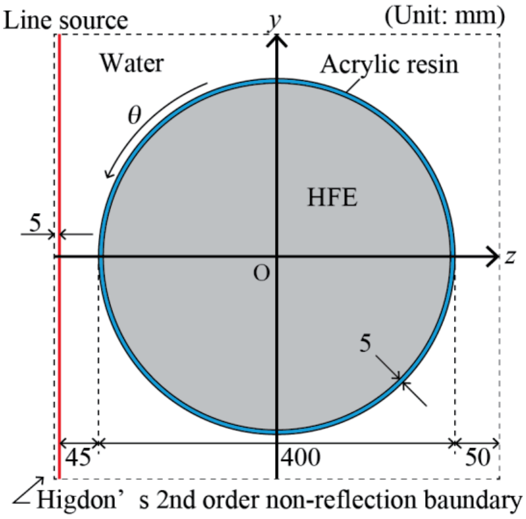

Fig. 1 Schematic view of the simulation and the lens.

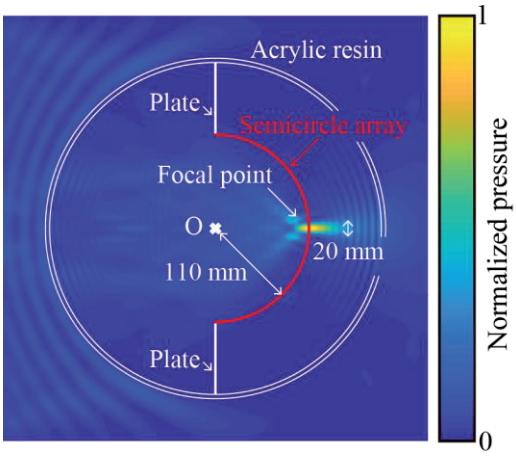

Fig. 2 Focsed pressure field and receiver array.

Table I Parameters of each medium.

	Verocity(m/s)	Density(kg/m^3)	Attenuation (Np/m)
Water	1500	1000	0
Acrylic resin	2700	1140	1.36
HFE	630	1680	0

A focused pressure field is shown in **Fig. 2**. The focused pressure field was calculated as the root-mean-square (RMS) of the sound pressure over the entire calculation time. The focal point is made inside of the lens because HFE has a high refractive index. The distance between the origin and the focal point is 110 mm. Therefore, a semicircle transducer

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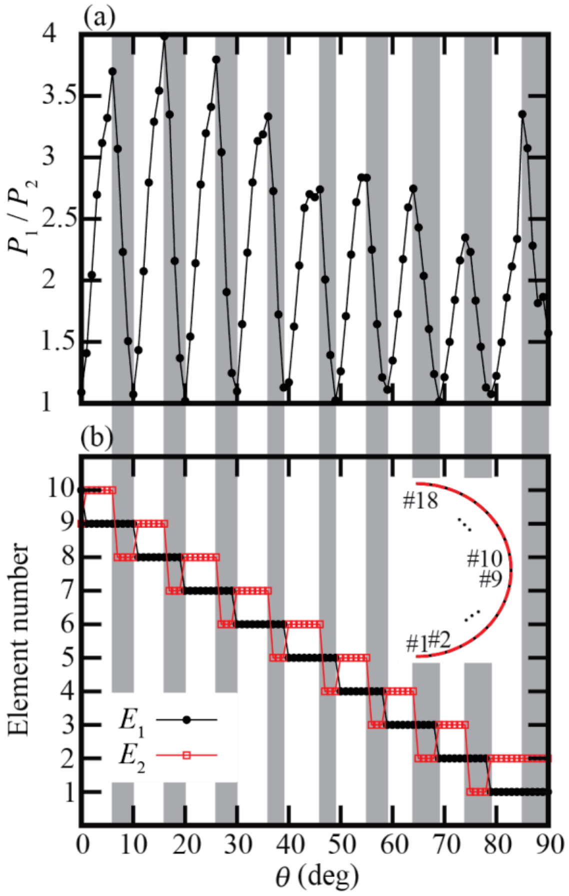

Fig.3 Calculation results for direction estimation: (a) relationship between θ and P_1 / P_2, and (b) relationship between θ and the element number.

array with a radius of 110 mm was designed to match the focal point. Additionally, two plates are arranged edges of the array to avoid diffraction to the rear of the array. The array and the plates are assumed to be rigid. Hereafter, the sound pressure in front of the array is treated as the received signal of the array. The element number is 18 and the element size is about 20 mm, which agrees with the main lobe width of focal point. In this condition, the main lobe can be received by at most two elements. The received signal of one element is obtained by integrating the sound pressure at the nodes of the simulation. The outputs are the 18 received signals down-converted to 250 kHz.

3. Positioning

In this paper, only the directional estimation is discussed due to the effectiveness of the lens, and the ranging is omitted since it is performed by ToF as in existing methods.

The azimuthal resolution depends on the beam width or the array element size and becomes 10° because the 180° angle of view is seen by the 18 elements, which is insufficient for the accurate direction estimation. Therefore, we attempt to improve the resolution using the ratio of the amplitudes of adjacent two elements in the following process. (1) Find the element which indicates the highest RMS of the sound pressure. The element number and the RMS value are defined as E_1 and P_1 respectively. (2) Find the element with the next highest RMS of sound pressure from the adjacent elements. The element number and the RMS value are defined as E_2 and P_2. (3) Calculate the ratio of the two RMS values as P_1 / P_2 .

The relationship between the angle of incidence θ and the ratio of the RMS values P_1 / P_2, and the element numbers E_1 and E_2 are shown in **Fig. 3**. When the angle of incidence θ increases, the ratio of the RMS values P_1 / P_2 shows the cyclical changes as shown in Fig. 3(a). If there is a main lobe between the two elements, P_1 and P_2 will have approximately the same value, indicating P_1 / $P_2 = 1$. If one element receives the main lobe, the ratio becomes larger. In the periodic change of the ratio P_1 / P_2, the dip-to-peak and peak-to-dip were painted white and gray. When Fig. 3(b) is painted the same pattern, $E_2 = E_1 + 1$ in white areas, and $E_2 = E_1 - 1$ in the gray areas. Therefore, the azimuthal resolution becomes more accurate than the resolution depending on the element size by using the combination of the element numbers E_1, E_2 and the ratio P_1 / P_2. However, when the angle of incidence θ is larger than 80°, the proposing method cannot be used because the condition, $E_2 = E_1 - 1$ in the gray area, is not satisfied.

4. Conclusion

We proposed UWA positioning method using a wide-angle acoustic lens. The array shape and the received signals were calculated using the 2-D FDTD method. The azimuthal resolution was improved by using the received signals at two adjacent elements when the angle of incidence was smaller than 80°.

However, this investigation was conducted without considering reflections outside the lens or multiple communication partners. These are future problems.

Acknowledgment

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