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Simulation of Underwater Acoustic Communications Under Reflective Environment Using a Parabolic Receiver

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1. Introduction

Underwater acoustic (UWA) communication is an essential technology to network underwater drones and sensors for more efficient underwater exploration. In UWA communication, omnidirectional transducers are typically used to cover large areas where the exact location of the transmitter and receiver is unknown. However, the use of omnidirectional transducers requires massive transmission power and complicated signal processing[1)]. On the other hand, the use of directional transducers is attracting considerable attention recently, since it has the potential to achieve low-power and simple communication[2,3)].

In this paper, we evaluate the possibility of UWA communication using parabolic reflectors as directional transducers under reflective environments by simulation. We have found that the use of reflectors can improve communication quality under reflection-free environments through simulation and experiments[4-6)]. However, evaluation in environments where reflections exist has not yet been conducted. Therefore, in this paper, simulations are conducted to evaluate the performance of UWA communications using directional transducers under reflective environments.

2. Parabolic Reflector

A parabolic reflector used in this simulation is shown in **Fig. 1**. The directional transducer consists of the reflector and three transducers[5,6)]. The aperture diameter of the paraboloid is 3.0×10^{-1} m and the focal length is 7.5×10^{-2} m. The aperture surface and the focal point lie on the same plane, where a transducer is placed at the focal point.

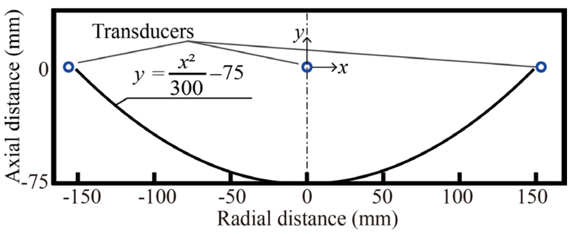

Figure 1: Parabolic reflector.

3. Simulation

Simulation of underwater acoustic communication using parabolic reflectors was conducted. **Table 1** shows the simulation conditions and **Figure 2** shows the simulation environment. Two-dimensional space of $4.5 \times 1.5\ \mathrm{m}^2$ was defined, and wave propagation was calculated using the finite-difference time-domain (FDTD) method. The boundary conditions for the outer perimeter of the computational space were set so that the left and right edges were Higdon's second-order absorbing boundaries, the upper edge was total reflection with zero sound pressure at the boundary, and the lower edge was total reflection at the free edge. The reflector was assumed to be a rigid wall.

Table 1: Simulation conditions

Simulation method	WE-FDTD
Spatial discretization step	1.2 mm
Time discretization step	0.48 μm
Number of elements	3750×1250
Speed of sound	1482 m/s
Number of steps	44508
Input signal	up-chirp, 75 – 85 kHz 5 ms
Training sequence	100 bits
Message	200 bits
Modulation	QPSK
Equalizer	RLS-DFE (FF: 41, FB: 40 taps)
Carrier frequency	80 kHz
Bandwidth	5 kHz

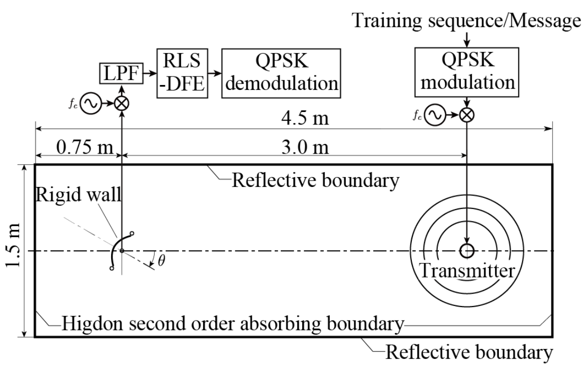

Figure 2: Simulation environment.

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First, the impulse response between the transmitter and the reflector was calculated. Specifically, a chirp signal (center frequency; 80 kHz, bandwidth; 10 kHz) was transmitted from the transmitter. The angle of the reflector was changed from -90° to 90° ($\theta = 0°$ when the transmitter and the reflector were facing each other). The center of rotation was the central transducer. The signal was received by the central transducer. and the impulse response of the channel was obtained by calculating the cross-correlation function between the transmitted and received signals.

We next evaluated a relationship between incident angle θ and communication quality. The received signal was calculated by convolving the impulse response obtained by the calculation with the signal modulated using single carrier modulation using parameters summarized in Table 1. White Gaussian noise was then added to the received signal. Finally, the receiver performed demodulation and equalization using a single-channel RLS-DFE equalizer (forgetting factor: 0.98). The output signal-to-noise ratio (OSNR) was used to evaluate communication quality.

The results of the simulation are shown in **Figs. 3 and 4**. Figures 3 and 4 show the angle of the reflector and the communication quality results. We first focus on the relationship between incident angle θ and ISNR. Figure 3 shows the ISNR with a reflector (solid line), its mean value (dotted line), and that without a reflector (single-dotted line). As shown in the figure, the ISNR in the case of a reflector is partially lower than in the case of no reflector, but on average it is higher. We next focus on the relationship between θ and OSNR. Figure 4 shows the OSNR with a reflector (solid line), its mean value (dotted line), and that without a reflector (single-dotted line). From this figure, we found that the OSNR with the reflector outperformed that without the reflector for $-70° \leqq \theta \leqq 70°$. The reason why there are multiple angles other than 0° at which the communication quality improves is thought to be because the reflected component of the boundary surface reaches the reflector. The peaks move outward according to the number of reflections on the boundary surface.

4. Conclusions

UWA communication using parabolic reflectors was evaluated by simulations. As a result, we found that UWA communication using parabolic reflectors can become a viable option for low-power and simple communication under reflective environments.

Acknowledgment

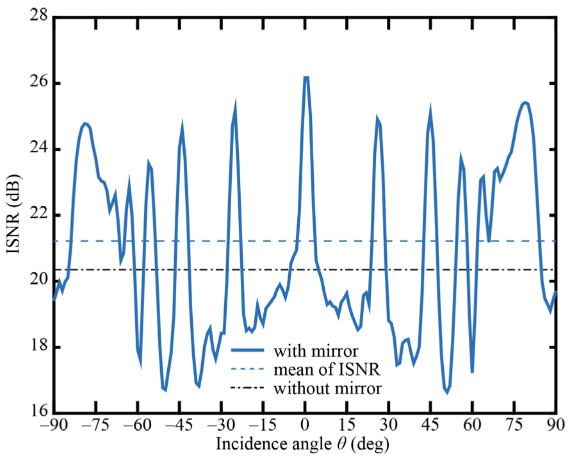

Figure 3: Simulation results; relationship between incidence angle θ and ISNR.

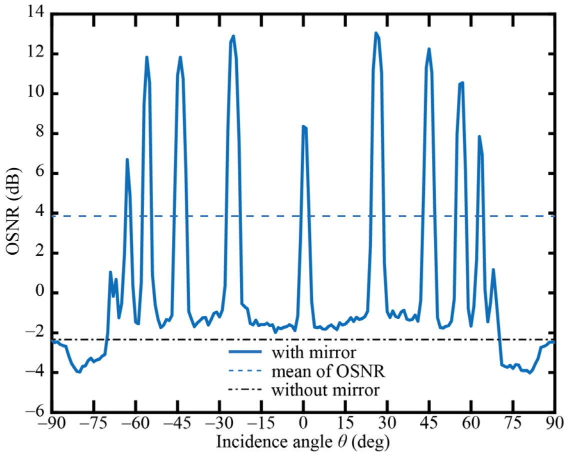

Figure 4: Simulation results; relationship between incidence angle θ and OSNR.

This work was supported by JST SPRING, Grant Number JPMJSP2124 and JSPS KAKENHI Grant Number JP19H02351.

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