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Simulation of Underwater Acoustic Communication Using Parabolic Reflector in a Multipath Environment

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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[1,2]. 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. 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[3].

In this paper, we evaluate the performance of UWA communication using parabolic reflectors as transmitter and receiver in a multipath environment by simulation. We have found that the use of a reflector as a receiver can improve the communication quality through simulations and experiments[4,5]. However, evaluation of the use of reflectors for both the transmitter and receiver has not yet been conducted. In this paper, we perform simulations with a reflector of multiple angles and without a reflector, and evaluate the communication quality in each case.

2. Simulation using a parabolic reflector

Figure 1 shows a two-dimensional parabolic reflector used in this paper. The parameters to be determined for the parabolic reflector are the signal wavelength, focal length, and aperture. The signal wavelength is 24 mm (f_c = 62.5 kHz), which has been used in UWA communications. While the aperture must be sufficiently larger than the wavelength to form an acoustic beam, it is necessary to consider portability. Therefore, the aperture diameter was set to 300 mm, which is about 13 times the wavelength. The transducer is omnidirectional and its y-coordinate is the same as the circumference of the parabola to take advantage of existing transducers and for ease of installation.

Simulation of UWA communication using the designed parabolic reflector is conducted. **Table 1** shows the simulation conditions and **Fig. 2** shows the simulation environment. First, the simulation conditions are described. A space of 31×12 (m^2) is defined, and directional transducers with parabolic reflectors are installed as shown in Fig. 2. The boundary conditions around the perimeter of the computational space are Higdon's second-order absorption boundaries on the left and right sides, and the top and bottom are reflective boundaries.

The transmitter outputs a chirp signal with a sweep frequency of 57.5 – 67.5 (kHz) and a time length of 5 ms from the directional transducer, and the receiver observes signal with the directional transducer. The impulse response of the channel is obtained by calculating the cross-correlation function between the transmitted and received signals. The convolution of the communication signal (calculated using the parameters shown in Table 1) and the impulse response of the communication channel is calculated, and the received signal and input signal-to-noise ratio (ISNR) are obtained by adding the white Gaussian noise with constant variance. Finally, the output signal-to-noise ratio (OSNR), which is an indicator of communication quality, is obtained by comparing the message obtained by demodulating the received signal with the transmitted message.

The above operations were repeated while changing the angle of the transmitter ϕ from 0, 5, ⋯, 90 (°), and the impulse response, ISNR and OSNR were obtained at each angle. The receiver

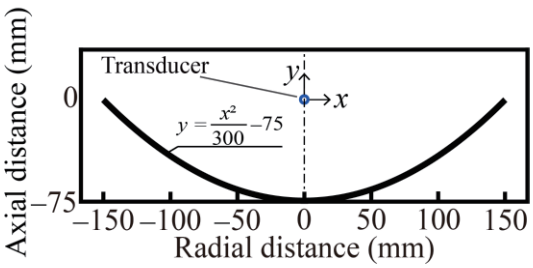

Figure 1: Parabolic reflector.

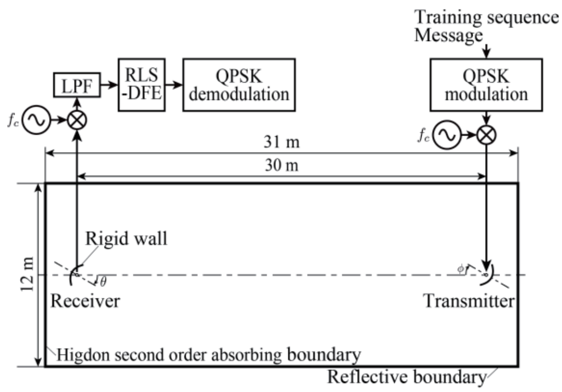

Figure 2: Simulation environment.

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Table 1 Simulation conditions.

Parameters	Values
FDTD	
Simulation method	WE-FDTD
Spatial discretization step	2.4 mm
Time discretization step	1.0 μs
Number of elements	12,917×5,000
Speed of sound	1482 m/s
Number of steps	166,906
Channel measurement	
Input signal	Chirp, 57.5–67.5 kHz
Signal length	5 ms
Communication	
Training sequence	100 bits
Message	200 bits
Modulation	QPSK
Equalizer	RLS-DFE
FF/FB	150/151 taps
Carrier frequency	62.5 kHz
Bandwidth	1.25 kHz

angle θ was set to 0 and -20 (°). Moreover, we also consider the case where an omnidirectional transducer was used.

3. Results

Simulation results are shown in **Figs. 3 and 4**. The solid, dashed, and single-dashed lines in Fig. 3 illustrate the relationship between the transmitter angle and ISNR for the directional transducers set at $\theta = 0°$, $\theta = -20°$, and the omnidirectional transducer, respectively. As shown in the figure, the ISNR with the reflector is improved by 3 - 15 (dB) compared to the ISNR without the reflector. When the receiver angle θ is -20°, the ISNR improves by 2 - 16 (dB) compared to the ISNR without the reflector. Also, the ISNR at a receiver angle of -20° was maximum when the transmitter angle was 20°, which is considered that there is a transducer – surface – receiver path.

The solid, dashed, and single-dashed lines in Fig. 4 illustrate the relationship between the transmitter angle and OSNR for the directional transducers set at $\theta = 0°$, $\theta = -20°$, and the omnidirectional transducer, respectively. As shown in the figure, the OSNR with the reflector is improved by 1 - 11 (dB) compared to the OSNR without the reflector. When the receiver angle is -20°, the OSNR improves by 3 - 17 (dB) compared to the OSNR without the reflector. Also, the OSNR at a receiver angle of -20° was maximum when the transmitter angle was 20°, which is considered to be due to reflected waves.

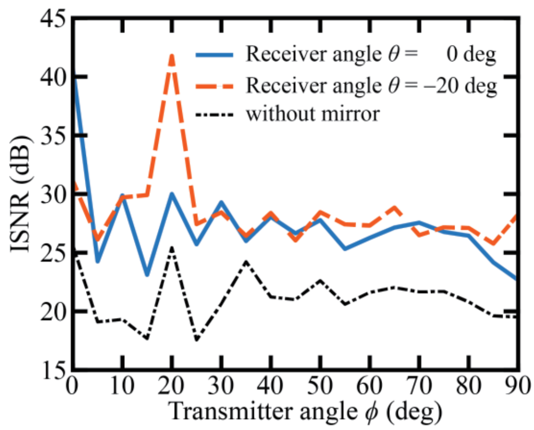

Figure 3: Simulation results; relationship between angle of transmitter and ISNR.

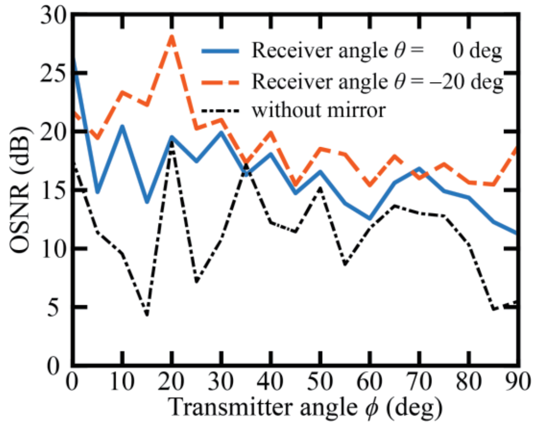

Figure 4: Simulation results; relationship between angle of transmitter and OSNR.

4. Conclusion

We evaluate the performance of UWA communication using parabolic reflectors as transmitter and receiver in a multipath environment by simulation. As a result, we found that UWA communication using parabolic reflectors for both transmitter and receiver can become a viable option for low-power and simple communication.

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