1P6-4

Measurement of Distance between Transmitter and Receiver Using Propagation Time of Underwater Acoustic Communication Signals with Orthogonal Signal Division Multiplexing Scheme

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1. Introduction

Utilization of underwater drones for performing various underwater tasks remotely, such as underwater exploration and inspection attract many researchers. Among many technologies that support remote operation of underwater drones, underwater positioning is indispensable. In underwater acoustic (UWA) positioning, a transmitter (Tx) with unknown coordinates transmits an acoustic signal, and a receiver (Rx) with known coordinates receives the signal, calculates the distance between the Tx and Rx based on the propagation time of the acoustic wave, and determines the position of Tx. Existing positioning systems often use phase-shift keying (PSK) modulation signals of Maximal-length-sequence (M-sequence)[1,2]. These methods can provide accurate positioning in deep waters, where the effect of reflected waves is small. However, in shallow waters, the large delay and Doppler spreads make communication and positioning difficult with existing methods.

To cope with of delay spread and Doppler issues, we propose an UWA positioning technique with orthogonal signal division multiplexing (OSDM), which is a robust communication scheme against delay and Doppler spreads[3]. In this paper, we construct an UWA ranging system utilizing OSDM, and evaluate the performance of the proposed system by simulation.

2.Proposed ranging system

Figure 1 shows a block diagram of the proposed ranging system. The Tx calculates a data vector $\boldsymbol{d}$ as

$$\boldsymbol{d} = \left(\boldsymbol{p}, \boldsymbol{0}_{1\times M(2Q+1)}, \boldsymbol{m}_0, \ldots, \boldsymbol{m}_{P-1}, \boldsymbol{0}_{1\times M(2Q+1)}\right),$$

where $\boldsymbol{p}$ is a pilot signal shared between Tx and Rx in advance, Q is a maximum Doppler shift that can be handled, $\boldsymbol{m}_p$ $(p = 0,1,\ldots,P-1)$ is a message data vector. Length of both of the $\boldsymbol{p}$ and $\boldsymbol{m}_p$ is M. Then, the Tx calculates a vector $\boldsymbol{x}$ by applying spreading matrix to $\boldsymbol{d}$ as

$$\boldsymbol{x} = \boldsymbol{d}(\boldsymbol{F}_N \otimes \boldsymbol{I}_M),$$

where $N = 1 + 2(2Q+1) + P$, $\boldsymbol{F}_N$ is an inverse discrete Fourier transform matrix of size N, $\otimes$ represents a Kronecker product, and $\boldsymbol{I}_M$ is an identity matrix of size N. The Tx emits $\boldsymbol{x}$ to a UWA channel. The transmitted signal is affected by delay and Doppler spreads and noise in the channel.

In existing OSDM scheme, the Rx utilizes received signal $\boldsymbol{y}$ only in demodulation processing. On the other hand, in our proposed system, the Rx also utilizes it for ranging. The Rx prepares a data vector $\boldsymbol{d}_{\mathrm{corr}}$ whose message part consists of $\boldsymbol{0}_{1\times M}$ as

$$\boldsymbol{d}_{\mathrm{corr}} = \left(\boldsymbol{p}, \boldsymbol{0}_{1\times M(2Q+1)}, \boldsymbol{0}_{1\times MP}, \boldsymbol{0}_{1\times M(2Q+1)}\right),$$

and calculates a reference OSDM signal $\boldsymbol{x}_{\mathrm{corr}}$ as

$$\boldsymbol{x}_{\mathrm{corr}} = \boldsymbol{d}_{\mathrm{corr}}(\boldsymbol{F}_N \otimes \boldsymbol{I}_M).$$

Then, the Rx calculates the cross-correlation between $\boldsymbol{y}$ and $\boldsymbol{x}_{\mathrm{corr}}$. Through the peak detection of obtained cross-correlation function, the Rx calculates the propagation time of the communication signal. Finally, the Rx obtains the distance between Tx and Rx $\hat{d}$ from the speed of sound and the sound propagation time. This system can measure the distance without deterioration of communication quality of OSDM scheme.

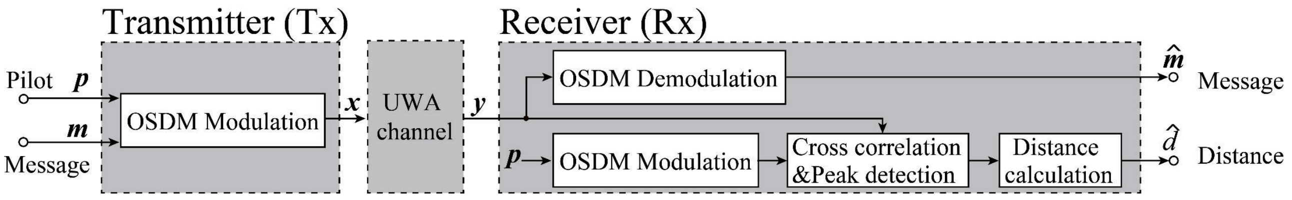

Figure 1 Block diagram of proposed ranging system

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3. Simulation

3.1 Simulation Condition

We conducted an UWA communication and ranging simulation with OSDM (proposed) and single-carrier modulated M-sequence using PSK (existing) to evaluate proposed system in shallow water. **Fig. 2** and **Table 1** show the simulation environment and parameters used in the simulation, respectively. The impulse response of the UWA channel was calculated based on ray-theory in which the reflection coefficients of the sea surface and sea bottom are -1 and 0.178, respectively. Specifically, the Received signal $\boldsymbol{y}$ was calculated by convolution of the transmitted signal $\boldsymbol{x}$ with the UWA channel impulse response. The Tx was assumed to move at a speed of 4 m/s so that the distance to Rx varied from $50 - 4.0 \times 10^3$ (m).

3.2 Simulation Result

Figure 3 shows a relationship between Tx-Rx distance and ranging error. Mean-absolute-error (MAE) of proposed and existing system are 0.417 and 0.333 (m), respectively. The variance of proposed and existing system are 0.483 and 0.564, respectively. As shown in the Figure 3, ranging using OSDM has almost the same accuracy to that using M-sequence. There exist several points at which the ranging error increases. At these distances, the direct and reflected waves on the sea surface reach Rx with almost the same magnitude, resulting in change of peak position.

Figure 4 shows a relationship between Input SNR and bit-error-rate (BER). As illustrated in the Figure 4, the proposed system has also achieved communication while ranging. From these results, UWA ranging system with OSDM achieved the same level of ranging accuracy as the conventional method without sacrificing communication quality.

4. Conclusion

In this paper, we proposed a system enabling simultaneous communication and ranging with OSDM scheme and verified its effectiveness through a simulation. As a result, the proposed system is capable of simultaneous communication while maintaining the same level of accuracy as existing ranging methods.

Acknowledgment

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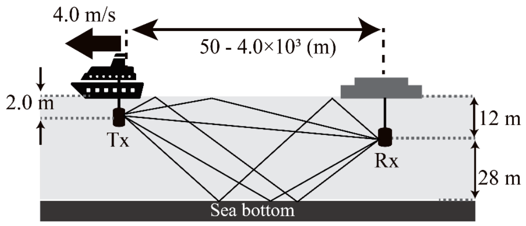

Figure 2 Simulation Environment

Table 1 Parameters used in simulation

Parameters	Values	
Scheme	OSDM	PSK
Modulation	QPSK	
Bandwidth	4.8 kHz	
Carrier Frequency	32 kHz	
Effective data rate	3.2 kbps	-
Speed of sound	1.5 km/s	

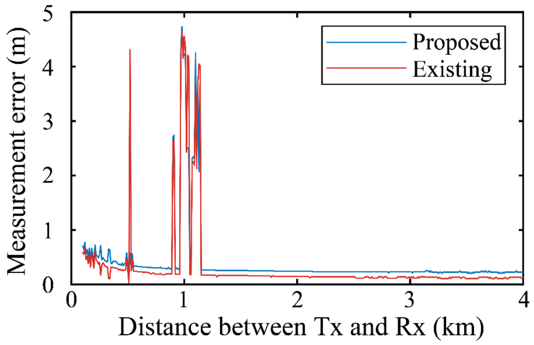

Figure 3 Relationship between Tx-Rx distance and measurement error of ranging

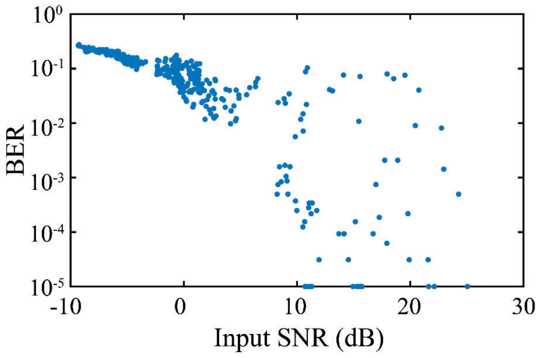

Figure 4 Relationship between Input SNR and BER

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