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Underwater acoustic communication performance of space-frequency diversity applying maximum ration combining with maximum likelihood estimation in time varying fading channel by the movement of underwater vehicle

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1. Introduction

The wireless underwater acoustic communication according to the movement of the underwater vehicle has performance variability due to the time-varying channel. [1)] Alos, the frequency of transmitted signals is also significantly distorted by transient Doppler effects generated by elongation and contraction of surface reflected transmission path, or Doppler frequency shifts from movement of either the transmitter and receiver. [2-3)]

In this paper, spatial-frequency diversity is applied to improve the performance according to the frequency selectivity of the underwater acoustic channel. The space-frequency diversity technique[4)] of frequency diversity using 5 channels and spatial diversity using 3 sensors was applied. The combining method for reconstruction is selected through maximum likelihood estimation, which provides the decision values of maximum ration combining and maximum ration combining.

2. The underwater acoustic channel

In wireless underwater acoustic communication, a transmission signal is received through a multipath by reflection of a channel boundary, and has a delay spreading and frequency selective characteristic of the received signal.

The frequency selectivity of the underwater acoustic communication channel can be expressed as a function of frequency and path length as shown in Eq. (1). [4,5)]

$$\Delta\emptyset = 2\pi(d_2\text{-}d_1)/\lambda \qquad (1)$$

Here, d is the path difference between the transmitter and receiver. λ is the wavelength.

This interaction between the two paths produces a frequency-selective fading, which can be expressed as a phase relationship as Eq. (2).

$$\Delta\emptyset = 2\pi(d_2\text{-}d_1)/\lambda = \pi \cdot 2(\mathrm{n}-1) \qquad (2)$$

Here, n is an integer representing a phase difference that is an odd multiple of π representing a frequency selective fade.

In addition, the Doppler frequency shift is defined as the ratio between the relative velocity between the underwater vehicle and the receiver and the propagation velocity of the signal. The signal with the Doppler transition due to the Doppler effect is expressed as follows.

$$r_D(t) = s((1+\Delta)t) \qquad (3)$$

3. Experimental and Results

This experiment was conducted in the water tank of the Marine Robot Center (L50*W20*H10) located in Gijang, Busan. **Figure 1** is an experimental ROV, and an underwater acoustic sensor was installed in the IWD6 ROV manufactured by CILab.

Fig. 1 IWD6 ROV.

The experimental parameters and configuration are shown in **Table I** and **Fig. 2**, respectively. The source and the receiver are located at depth of 2 m and 3 m and distance 5 m and 1.5 m, respectively.

Table **I**. The experimental parameters.

Modulation	4FSK_5channel
Carrier frequency (kHz)	16, 16.5, 17, 17.5,18
Bit rate(sps)	100 sps
Transmission bit(bit)	20000 bit
Distance(m)	5, 1.5
Transmitter / receiver depth	2 m, 3 m

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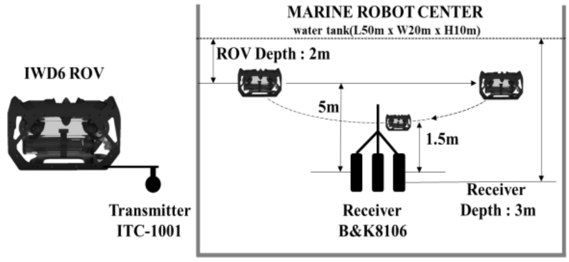

Fig. 2 The experimental configuration.

As shown in **Fig 3**, the frequency selectivity of the underwater acoustic channel was analyzed using the LFM (Liner Frequency Modulation) signal at the intervals of 1.5 m and 5 m of the ROV. In 1.5 m proximity communication, the effect of reflected wave was low, and the response characteristic of non-frequency selectivity was shown. At 5 m, the frequency selectivity increased under the influence of the reflected wave, which affected the transmission performance.

Figure 4 is analyzes the energy change of the mark frequency of each channel during the movement of the ROV.

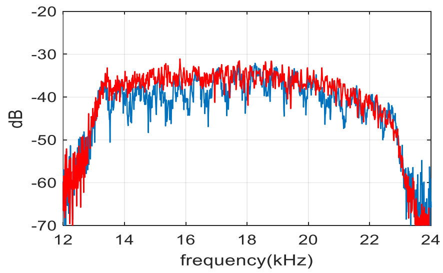

Fig. 3 Frequency selectivity according to ROV movement.

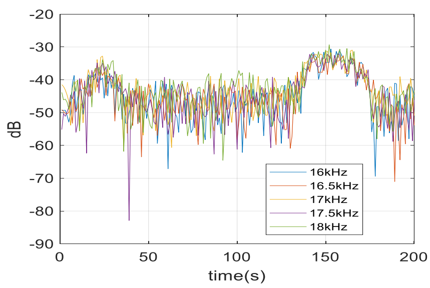

Fig. 4 Change of mark frequency energy of channel according to ROV movement.

Table II shows a demodulated image to which a frequency shift modulation method of space-frequency diversity is applied. The average BER was analyzed to be 0.13.

Table III shows an image demodulated after applying maximum ration combining to space-frequency diversity and an image demodulated after applying maximum ration combining with MLE. After applying maximum ration combining and MLE, the error was reduced and

Table II Demodulated image of frequency shift modulation of space-frequency diversity.

Frequency diversity / Space diversity	CH1	CH2	CH3	CH4	CH5
Sensor 1					
BER	0.13	0.11	0.12	0.12	0.14
Sensor 2					
BER	0.13	0.12	0.13	0.13	0.15
Sensor 3					
BER	0.12	0.12	0.12	0.12	0.13

Table III Space-frequency diversity and an image demodulated after applying maximum ration combining with MLE.

Space-Frequency diversity	Original	Freq. diversity	Space-Freq. diversity
maximum ration combining			
BER	-	0.06	0.06
maximum ration combining with MLE			
BER	-	0.04	0.03

the image demodulation performance was high.

4. Conclusions

In this paper, maximal ratio combining and maximum likelihood estimation are applied to space-frequency diversity to improve underwater communication performance. After applying maximum ration combining with MLE, an error of 50% was reduced, and the image demodulation performance was also high.

Acknowledgment

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References

1. M. Bae, J. Park, J. Kim, D. X. Xue, K. Park, and J. R. Yoon: Jpn. J. Appl. Phys. 55 (2016) 07KG03.
2. J. Esaki: Jpn. J. Appl. Phys. **46** (2006) 852.
3. H. Goldstein: *Classical Mechanics* (Prentice Hall, NJ, 2002) p. 122.
4. T. S. Rappaport, *Wireless Communications* (Prentice Hall PTR, New Jersey, 2002) 2th ed., p. 380.
5. S. Yoshizawa, T. Saito, Y Mabuchi, T. Tsukui and S. Sawada, Proc. IEEE OCEANS, (2018), 15.