1Pb6-3

Underwater Acoustic Communication between UUV and USV with Large Relative Velocity

Naruhiro IWAMA[1‡], Takaki YAMADA[1], Yukihiro KIDA[2], Mitsuyasu DEGUCHI[2], Takuya SHIMURA[2] ([1]ATLA; [2]JAMSTEC)

1. Introduction

Recently, Unmanned Underwater Vehicle (UUV) and Unmanned Surface Vehicle (USV) are widely used for practical applications in offshore development, such as seabed observations and infrastructure maintenance. In the future, collaboration of multiple unmanned maritime vehicles is expected for achieving more complex missions.

Since electromagnetic waves are attenuated severely in water, UUVs need to use acoustic communication to communicate with other UUVs or USVs. However, underwater acoustic communication (UAC) suffers from the Doppler shift more seriously than electromagnetic waves communication, because the underwater sound velocity is significantly slow. In addition, multipath waves caused by underwater reflection and refraction can decrease signal qualities.

Current UUVs are typically operated under the mother ships, so vertical UAC systems can be applicable for their communications.[1)] Naval Systems Research Center (NSRC) developed USV-UUV parallel cruising system where side scan sonar images are transmitted via vertical UAC .[2)] However, for UUV teaming where horizontal UAC is necessary, multipath waves are not negligible. It is known that Decision Feedback Equalizer[3)] (DFE) is effective in compensation of a multipath wave. NSRC demonstrated a horizontal UAC network between fixed nodes by reducing the multipath effect with DFE.

On the other hand, there are only limited studies on horizontal UAC between mobiles, where strong Doppler shifts occur. In order for two or more vehicles to carry out a concerted action, UAC with large relative vehicle velocity is indispensable.

In this research, the signal processing methods for compensating an effect of a Doppler shift were tested in the field experiments using UUV and USV, and their effectiveness was evaluated.

2. Methods for compensating a Doppler shift

Fundamental reduction of a Doppler shift is performed by measuring elasticity of a signal by detecting Zadoff-Chu sequence signals for synchronizing.[4)] To suppress detection failures caused by multipath waves, the signals are detected through the two-step correlation calculation.[5)]

In addition, Digital Phase Locked Loop (D-PLL) was implemented in DFE[6)] to evaluate its effectiveness against a Doppler shift.

3. Experimental devices

The transmitter was installed at the tip of the UUV (**Fig. 1**) and the receiver was installed in the dome at the bottom of the USV. The receiver consisted of 16 hydrophones.

The UUV and the USV are shown in **Fig. 2** and **Fig. 3** respectively. The vehicles were developed in the NSRC's research project described in Chapter 1. (manufacturer: IHI)

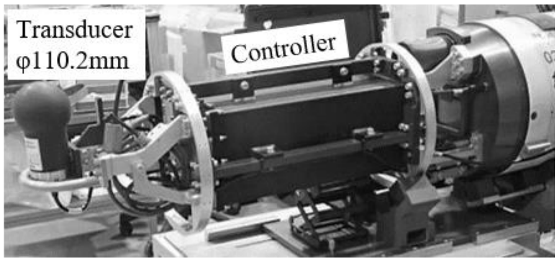

Fig. 1 The tip of the UUV without the cowl. The transducer and its controller for transmitting were fixed on the UUV frame.

Fig. 2 The UUV with the transmitter.

Fig. 3 The USV with the receiver in the dome at the bottom.

4. Experiment

The field experiments for evaluating the proposed UAC system were conducted at the Suruga bay in June-July and December, 2021. The depth of water was about 100 m, and the UUV cruised at the depth of 50 m. For the autonomous navigation, INS+DVL was used for the UUV and GPS was used for the USV.

At the beginning of each experiment, the UUV and the USV faced each other at a distance of 1000 m or more, then cruised and passed by each other. The UUV and the USV were turned up and passed by each other again (2 or 3 times). Their speeds were constant during each experiment. In the most challenging experiment, the relative velocity of 10 kt (UUV 5.5 kt + USV 4.5 kt) was designated.

The test signals were transmitted from the UUV and received by the USV. The received signals were recorded in the USV system and demodulated off-line for evaluation.

An example of the demodulation is shown in **Fig. 4**. The results for QPSK, 8PSK and 16QAM signals are shown from the left. The BPSK signals of the pilot data is contained in each result. Although the relative velocity during this experiment was about 10 kt so that a strong Doppler shift is expected, the test signals were successfully demodulated.

Another important point was revealed through the experiments based on the relationships between vehicles' log data and SNR. **Fig. 5** shows Input SNR, Output SNR and Distance between the UUV and the USV during an experiment. (Relative velocity: 10 kt) When the UUV and the USV approached each other, SNR increased gradually, but when they are separating, SNR decreased rapidly. This shows that the noises behind USV (probably caused by the water jet outboard motor) are not negligible for UAC between the vehicles, revealing the importance of considering communication directions.

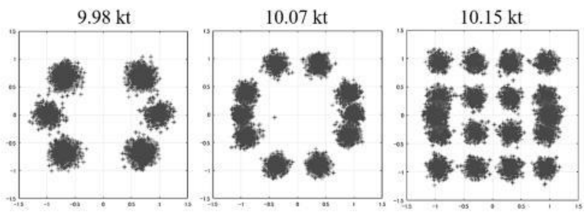

Fig. 4 The results of demodulation. The speed values are calculated based on the received signals.

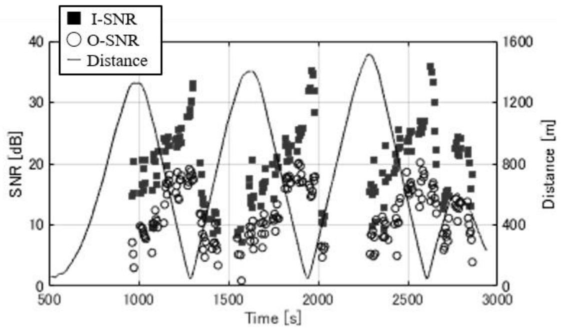

Fig. 5 Input SNR, Output SNR and Distance between the UUV and the USV.

5. Summary

The field experiments of horizontal UAC between unmanned vehicles (UUV and USV) were carried out in the sea. DFE and D-PLL were introduced for reducing the effects of multipath and Doppler shifts, and their effectiveness was evaluated. UAC at a relative vehicle speed of 10 kt was achieved. This result can be utilized for research programs in the future.

Acknowledgment

We would like to extend special thanks to the members of "Hitachi", "IHI", "SAS", "Shoshin" and "Oki Com-Echoes" who supported our experiments. The experiments are conducted in the research program "Study on mobile underwater acoustic communication" of NSRC from FY2019 to FY2021, under the research partnership agreement with Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

References

1. Y. Kida, M. Deguchi and T. Shimura: J. Mar. Acoust. Soc. Jpn. **45** (2018) 197.
2. N. Suzuki, H. Kitajima, H. Kaba, T. Suzuki, T. Suto, A. Kobayashi and F. Ochi: OCEANS 2015 (2015) pp. 1-6.
3. Y. Watanabe and H. Ochi: Jpn. J. Appl. Phys. **43** (2004) 3134.
4. 3GPP: *TS 36.211 V13.2.0* (2016) pp. 62-65.
5. Y. Akamine, S. Kondo, M. Nanri, H. Ochi: P2018-107742 (2018)
6. Z. Shaolong, Z. Chenguang, Z. Xuesan, W. Yongfeng and Z. Hong: 2014 IEEE ICSPCC (2014) pp. 359-362.