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At-sea experiment of underwater acoustic communication with a prototype of autonomous surface vehicle
自律型洋上航走体試作機を用いた水中音響通信の海域実験

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1. Introduction

Recently, concerns about mineral sources on the seabed have increased and prompted many efforts to survey them. For this reason, many autonoumous underwater vehicles (AUVs) have been deveoped and operated. In a conventional system, only one AUV is operated at a time because it is difficult for a supporting vessel to monitor the statuses and positions of multiple AUVs at one time throughout their dives. To make AUV surveys more efficient, an operational system with multiple AUVs and multiple autonomous surface vehicles (ASVs) has been proposed. [1,2] In this proposal, the survey system constitutes multiple pairs of an AUV and an ASV, and each ASV always monitors the status and a position of an AUV by using acoustic communication and localization. In addition, an ASV follows an AUV autonomously, making the survey area of each AUV wider. Furthermore, the ASV must be as small as possible, from an operational view, which can lead to it ASV rolling and pitching up a larger angle than a supporting vessel in a conventional system.

In this paper, a basic experiment using a prototype ASV was demonstrated in Suruga Bay. Signals of both the single carrier modulation (SCM) and orthogonal frequency domain multiplexing (OFDM) were transmitted to the ASV by a moored source in this experiment, and their performances were compared in terms of output SNR.

2. Experiment

2.1. Experimental set-up

The experiment was conducted in Suruga Bay using a prototype ASV, shown as **Fig. 1**. A source was moored at a depth of approximately 1700m, and the ASV revolved around a point at a distance of 450m from the moored point. The turning radius was 200m, and the speed was 2 knots. The course of the ASV is depicted in **Fig. 2**.

The source level was approximately 196dB, and the frequency band ranged from 16kHz to 24kHz. A receiver array with a size of 100mm*100mm and constituting of five elements was embedded on the ASV's keel.

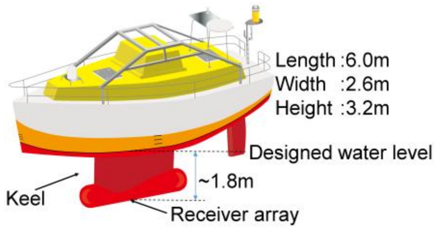


Fig. 1 A prototype of an ASV.

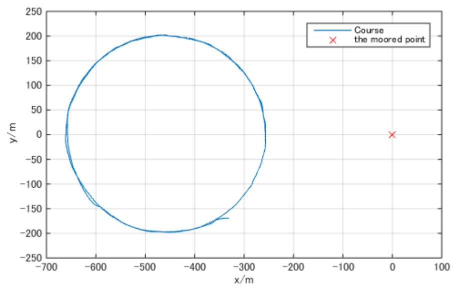
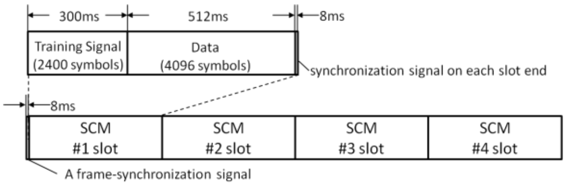


Fig. 2 The course of the ASV in this experiment. The blue line indicates the course at 2 knots and the red cross marks the point of the moored source.

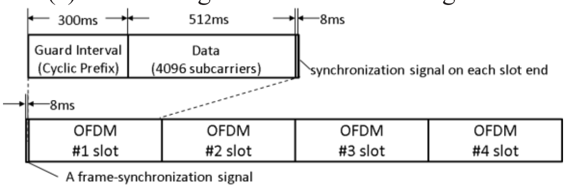
2.2. Modulation and demodulation

In this paper, SCM-QPSK and OFDM-QPSK signals were received by the ASV and demodulated in offline porcessing after recovery. The bandwidths of both the SCM and OFDM signals were 8kHz, and their carrier frequencies were 20kHz. Signal configurations are shown in **Fig. 3**.

Both signals are compensated for the doppler shift according to the estimated rusults using measurements of the slot duration before demodulation. In the SCM demodulation, a multi-channel decision feedback equalizer (Mch-DFE) was utilized to suppress the effects of multipath environments and their changes. [3,4] On the other hand, pilot symbols were inserted at every three subcarriers of the OFDM signals, and a zero forcing equalizer (ZFE) with pilot interpolation was utilized in OFDM demodulation.



(a) The configuration of the SCM signal

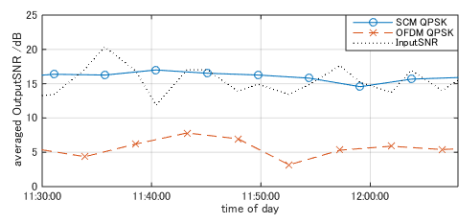


(b) The configuration of the OFDM signal

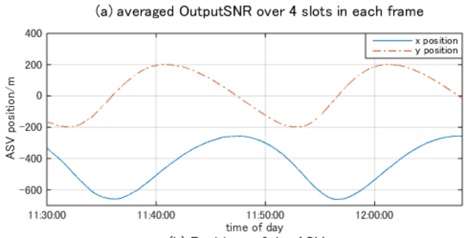
Fig. 3 Signal configurations. (a) indicates the configuration of the SCM signal and (b) denotes the configuration of the OFDM signal.

3. Results and Discussion

Fig. 4 (a) indicates the output SNR of both the SCM and OFDM signals, and (b) indicates the position of the ASV. They show that the output SNR of the SCM signals was higher than those of the OFDM signals by approximately 9dB. One possible reason for this is inter carrier interference caused by rolling and pitching for a slot duration. **Fig. 5 (a)** indicates the compensated phases of each channel by the digital phase lock loop (DPLL) combined with the DFE, in the case of #1 slot of the SCM-QPSK signal received at 11:45 in Fig. 4 (a), while **Fig. 5 (b)** indicates the evaluated Doppler shift based on the compensated phase by the DPLL. This demonstrates a variation of Doppler shift for a slot duration, which can cause inter carrier interference in the case of an OFDM signal, because the bandwidth of the subcarriers is approximately 2Hz. Although a shorter symbol duration is one of the ways to avoid interference, it causes a lower throughput because each guard interval cannot be shorter. Therefore, we found the SCM signals to be more effective for the proposal system than the OFDM signals.

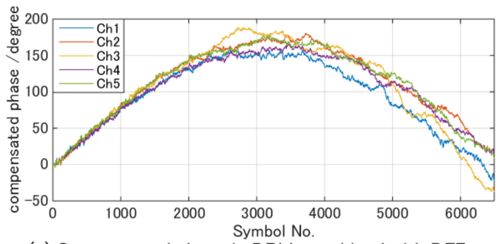


(a) averaged OutputSNR over 4 slots in each frame

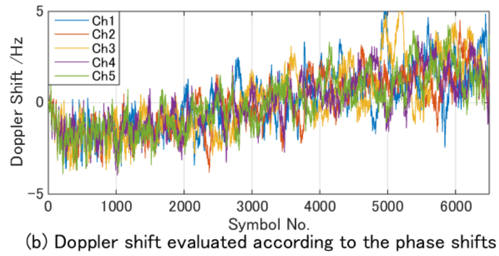


(b) Positions of the ASV

Fig. 4 Output SNR and ASV's positions. (a) indicates averaged output SNR over 4 slots in each frame and input SNR at each frame synchronization signal;(b) indicates the position of the ASV.



(a) Compensated phase in DPLL combined with DFE



(b) Doppler shift evaluated according to the phase shifts

Fig. 5 Compensated phases by the DPLL and the evaluated Doppler shift based on the phases. (a) indicates compensated phases of each channel by the DPLL. (b) shows the evaluated Doppler shift according to 100-point moving averages of the phases in (a).

4. Summary

In this work, a fundamental experiment using a prototype ASV was demonstrated in Suruga Bay, and both SCM-QPSK and OFDM-QPSK signals were applied. Consequently, the output SNR of SCM-QPSK signals was higher than those of OFDM-QPSK signals by approximately 9dB. One possible reason for this is inter carrier interference in OFDM signals caused by rolling and pitching for a slot duration.

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