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Preliminary Experiment of Acoustic Positioning in Shallow Water Based on Delay-and-Sum Beamforming Using Semi-circular Array

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1. Introduction

Recently, underwater positioning technology has gained attention as a means of supporting inspections with underwater drones by integrating inspection data and location information. In conventional underwater acoustic (UWA) positioning, the relative positions of a transmitter (Tx) equipped with an acoustic emitter and a receiver (Rx) equipped with a hydrophone array are determined by measuring the time-of-flight (ToF) or direction-of arrival (DoA), or a combination of both for acoustic signals. However, in shallow water, acoustic waves propagate with numerous reflections from the sea surface and seafloor, resulting in a multipath environment that complicates accurate measurement [1)].

To accommodate scenarios such as positioning an underwater drone from a small vessel, it is necessary to reduce the aperture of the hydrophone array. When the aperture of the hydrophone array is large, there is a challenge of decreased angular resolution. However, due to the relatively large size of the hydrophones, there are constraints on the aperture width. Traditionally, linear hydrophone arrays have been widely used, but issues have arisen due to the size of the hydrophones, the frequencies employed, and the limitations of the aperture diameter, leading to the generation of sidelobes and complicating accurate angle selection.

Therefore, this study investigates the application of delay-and-sum (DAS) beamforming for UWA positioning in shallow waters using a semi-circular hydrophone array with a smaller aperture diameter. Although DAS beamforming is widely used in underwater, its performance in extremely shallow water with a limited array aperture size has not been thoroughly investigated [2)]. In the following sections, we provide an overview of DAS beamforming, describe the experimental setup, present the experimental results, and discuss the findings.

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2. Overview of UWA positioning using DAS beamforming

Figure 1 shows an image of UWA positioning using DAS beamforming and a block diagram outlining the signal processing for both the Tx and Rx. It is assumed that the Tx and Rx are synchronized in time. The Tx modulates a maximal length sequence (M-sequence) using phase-shift keying and transmits the modulated signal $x(t)$ into the UWA channel. The transmitted signal propagates with multiple reflections before reaching the Rx. The Rx, equipped with N hydrophones, receives the signal and estimates the coordinates of the Tx using ToF and DoA measurements facilitated by DAS beamforming.

The details of DAS beamforming are as follows. To determine the DoA, the Rx computes the fast Fourier transform (FFT) of the received signal. By applying a steering vector corresponding to the array geometry and orientation, the Rx maximizes the array gain to identify the DoA. It is important to note that, due to the continuous movement of the underwater drone, prior DoA information is also integrated into the determination process alongside current measurements.

To determine the ToF, the Rx first measures the impulse response of the UWA channel from the Tx to each hydrophone. This is achieved by computing the cross-correlation function between the received signal and the transmitted signal. The ToF is then derived from the peak position of the impulse response, which reflects the time difference in signal arrival at each hydrophone, considering the DoA information determined earlier.

3. Experiments

To evaluate the performance of the proposed method, an experiment was conducted in Nabeta Bay, Shizuoka. As shown in Fig. 1, an emitter and 8 hydrophones were used. The Tx was installed on a mobile boat, the Rx on a breakwater, and the 8 hydrophones were mounted on an aluminum frame. During the experiment, the boat moved at a speed of 1-2 (m/s). The position of the Tx was measured using proposed positioning method and a real-time kinematic global positioning system (RTK-GPS).

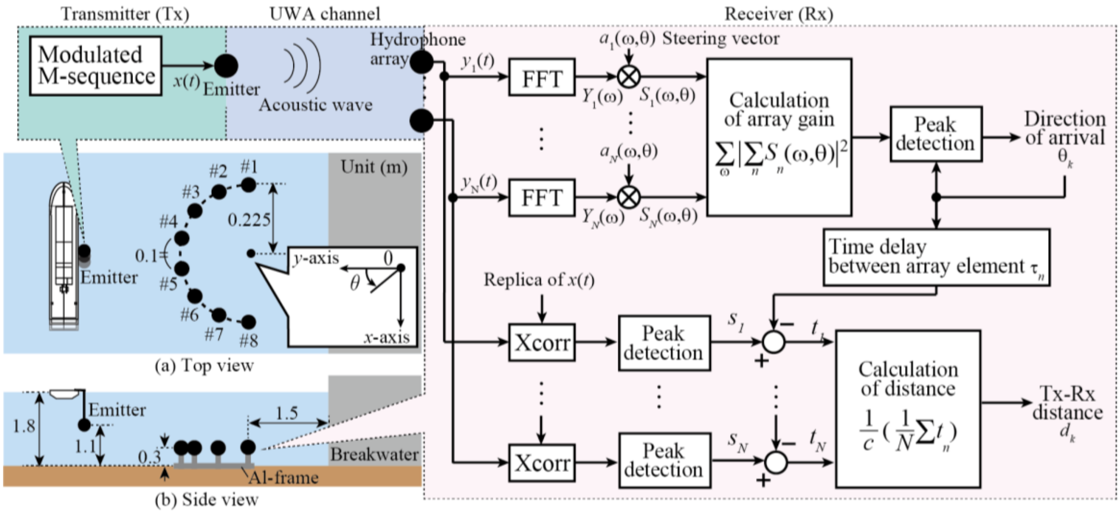

Fig. 1 Block diagram of signal processing and experimental setup.

4. Results

Figure 2 shows the experimental results. Figs. 2(a), 2(b), and 2(c) show the results of DoA estimation, distance estimation, and positioning estimation in steps 1400 through 1800 (pink area), respectively. The blue and orange lines in the figures represent the results obtained by the proposed method and the reference obtained by RTK-GPS, respectively. As shown in Fig. 2(c), the proposed method can provide accurate positioning in shallow water. Specifically, the mean absolute errors (MAE) for DoA and Tx-Rx distance were 3.47 degrees and 1.73 m, respectively.

However, as shown in Fig. 2(b), the distance error is extremely large around steps 400 and 1200. At this time, the signal-to-noise ratio (SNR) of the received signal was extremely small, and the increase of error is expected because propeller cavitation, which scatters the signal, exists on the acoustic path when the boat changes its direction.

5. Conclusion

In this study, we explored the application of DAS beamforming for UWA positioning in shallow water using a semi-circular hydrophone array. The experiment conducted in the coastal area achieved a MAE of 3.47 degrees in DoA and 1.73 m in Tx-Rx distance. However, errors increased due to propeller cavitation, resulting in low SNR. These results demonstrate that DAS beamforming can be effective for integrating inspection data and coordinate information in practical underwater inspections using underwater drones.

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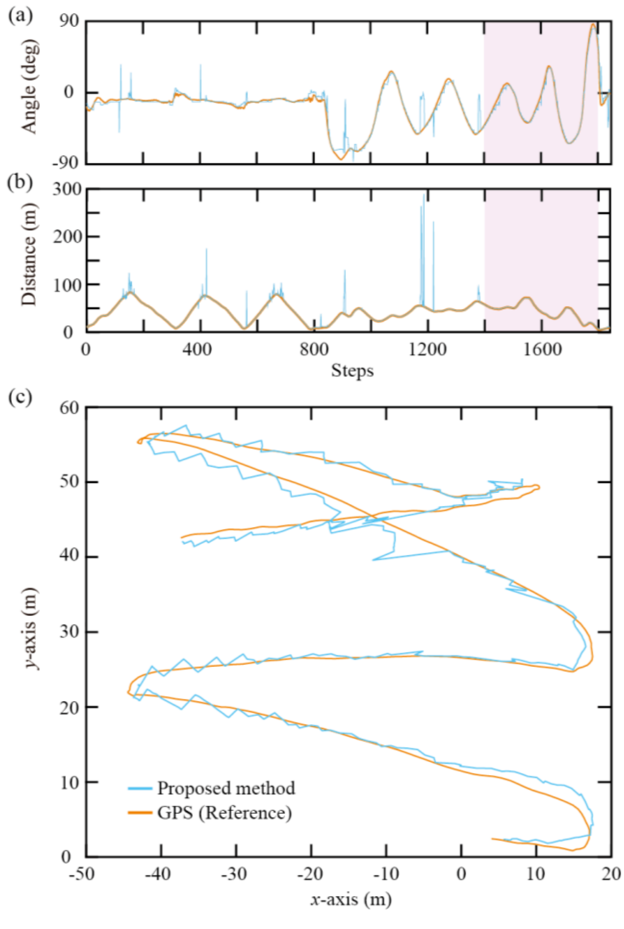

Fig. 2 Experimental results; Estimation of (a) DoA, (b) distance, and (c) 2D position in pink area.

References

1) Y. Sato, T. Ebihara, N. Urasaki, K. Mizutani, and N. Wakatsuki, *Jpn. J. Appl. Phys*. **63**, 05SP07
2) Y. Watanabe, H. Ochi, T. Shimura, and T. Hattori, *Jpn. J. Appl. Phys*. **49**, 07HG13 (2010).