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Experimental analysis of underwater acoustic source localization using closely spaced hydrophone pairs

Min Seop Sim[1†], Byoung-Nam Kim[1], Eung Kim[1], Bok-Kyoung Choi[1], and Kyun Kyung Lee[2]
([1]Korea Institute of Ocean Science and Technology; [2]Kyungpook National Univ.)

1. Introduction

Underwater sound source position is determined using a line array like the TASS, frank array using the beamforming and band analysis[1,2]. However, performance degradation occurs owing to a multipath environment, which generates incoherent signals[3,4]. In this paper, a hydrophone array is proposed for underwater source position estimation robust to a multipath environment. For verification of the proposed array, we perform experimental analysis with the conventional array. The proposed system is not affected by a multipath time delay because of the close distance between closely spaced sensors. The array is composed of three pairs of sensors that are a coupled of closely-spaced hydrophone placed on the same line. The source position is estimated by performing generalized cross-correlation (GCC) and wavefront curvature analysis[5]. The validity of the array is confirmed by experiment.

2. Geometry of array

The geometry of array between target and closely-spaced hydrophone pairs is shown as **Fig. 1**.

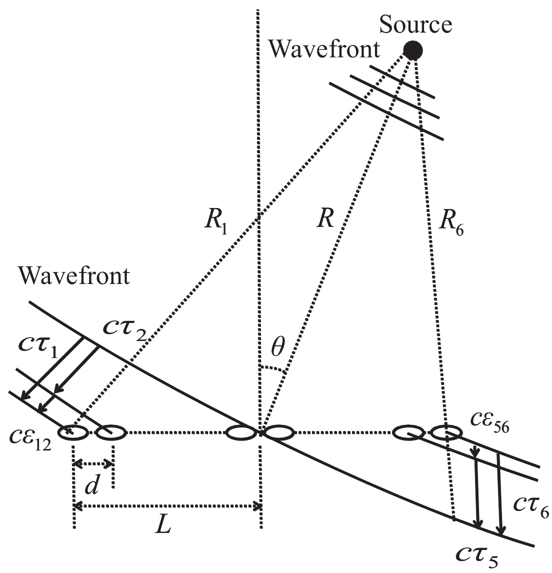

Fig. 1 Geometry of array.

kklee@ee.knu.ac.kr

The location of acoustic source from array can be written

$$R = \frac{2L(d^2 - c^2\varepsilon_{34}{}^2)}{cd(\varepsilon_{12} - \varepsilon_{56})},$$

$$\theta = sin^{-1}\left(\frac{c\varepsilon_{34}}{d}\right),$$

where the sound speed is c, the time-delay between closely spaced sensor is ε_{12}, ε_{34}, ε_{56}. The distance between widely spaced hydrophones is L and that between closely spaced hydrophones is d.

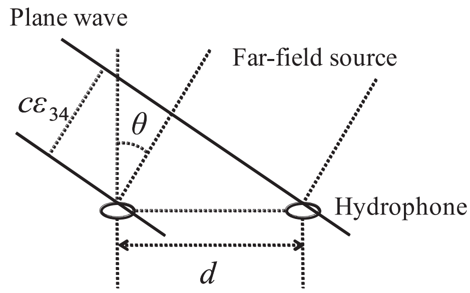

Fig. 2. Geometry of closely spaced hydrophone pair.

The signals transmitted from an underwater object undergo different propagation paths that cause distortion of the signals through reflections and diffractions on the sea surface and bottom. Consequently, each received signal on widely spaced sensors has noncoherent characteristics, which cause performance degradation in the estimation of the time delay. However, by using the proposed array structure, we can obtain the time difference of received signals from generalized cross-correlation (GCC) in a multipath environment without degradation. The signals acquired from the sensor pairs are coherent owing to the sufficiently short distance between the closely spaced hydrophones, such that different propagation paths can be ignored[6].

3. Experiment setup

For verification of the proposed array, we perform experiment using spherical acoustic signals in the multipath environments. The depth of the water tank is 1 m. The bearings and ranges of the target are assumed to be 0-20° and 0.82 m from hydrophones. The underwater source depth and receiver depth are 0.5 m and 1 m. The distance between widely spaced hydrophones is 0.3 m and that between closely spaced hydrophones is 0.05 m. The center frequency of the signal and the length of a continuous wave (CW) pulse are 30 kHz and 1 ms, respectively.

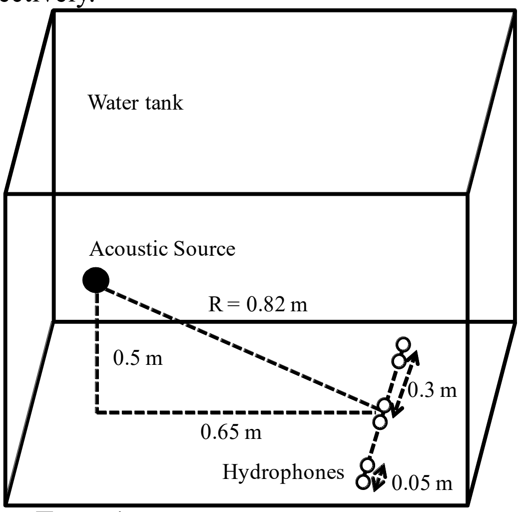

Fig. 3 Experiment setup

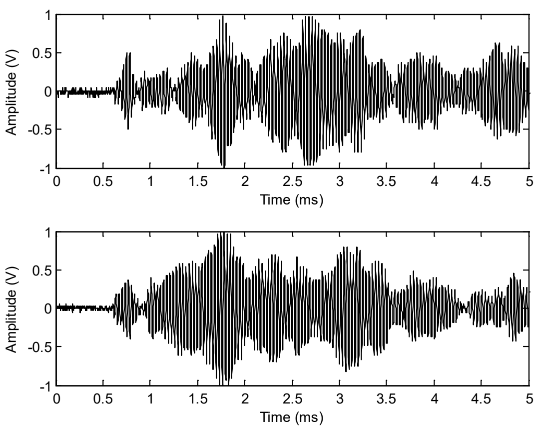

Fig. 4 Examples of received signal affected by multipath environment at the sensor 3 and 4(signal frequency = 30 kHz, signal length = 1 ms).

4. Experimental analysis

Table I and **II** are experiment results of the conventional array, which is composed of three widely spaced hydrophones, and the proposed array for estimating the time difference between received signals, underwater source bearing, and range from the array. The estimated values are compared by changing array to confirm the efficiency of the array of closely spaced hydrophone pairs under multipropagation condition. Under the multipath condition, the closely spaced sensor array performs better than the conventional array in terms of bearing and range estimations. The closely spaced hydrophone pair array showed better performance in the multipath environment. It is due to the improvement of signal coherence.

Table I. Average values of estimated ranges and bearings at proposed array and conventional array.

	Proposed array	Conventional array
Estimated range	0.81 m	1.80m
Estimated bearing	7.12 °	7.50 °

Table II. RMSEs of estimated ranges and bearings at proposed array.

	Range	Bearing
RMSE	0.032 m	0.26 °

5. Conclusion

We propose closely-spaced hydrophone pairs array to find the underwater acoustic source location using time-delay at hydrophone pair. We can confirm by experiment using simple signal processing that this line array system can find the target efficiently in a multipath environment. It is necessary to verify the proposed method under more severe conditions, because the simulations and experiments in this study were conducted under limited conditions. Also, we have to use various methods to find the time difference between signals and compare the results with those obtained using other systems.

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