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Underwater Acoustic Source Localization using Closely-spaced Hydrophone Pairs

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1. Introduction

A lot of array is available to estimate the underwater acoustic source localization. Source position is found by line array like the TASS, frank array using the beamforming and band analysis. In case of, LBL(Long Base Line), SBL(Short Base Line), USBL(Ultra Shortt Base Line) system are widely used for military, industrial purposes by accuracy of estimation take a advantage of pinger. In this study, closely-spaced hydrophone pairs array is proposed for underwater source position estimation. Array is composed of 3 pairs placed on equivalent line that are a coupled of closely-spaced hydrophone. The point of acoustic source is estimated by performing wavefront curvature analysis and geometry analysis[1,2,3]. Proposed array is not affected by multipath signal because of distance between closely-spaced sensor. The validity of the array is confirmed through the simulation which is use the acoustic signal synthesized by eigenray.

2. Geometry of array

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

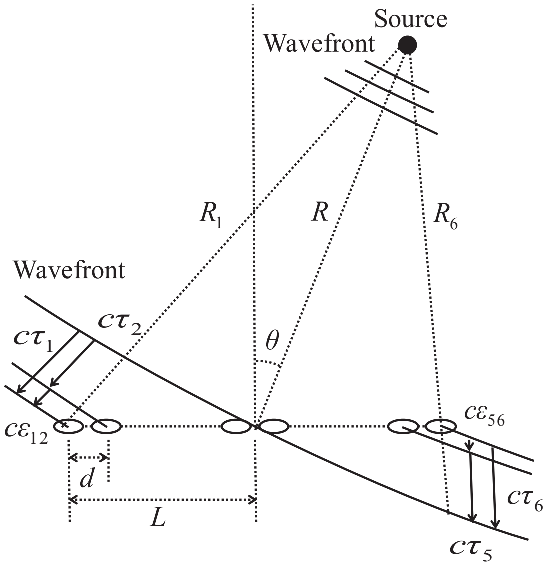

Fig. 1 Geometry of array.

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For the range of acoustic source from array, distance R_1 and R_6 are respectively,

$$R_1 = R + c\tau_1$$

$$R_6 = R + c\tau_6$$

where the sound speed is c, the time-delay between source and sensor is τ. Each time-delay can be written

$$c\tau_1 = \sqrt{R^2 + L^2 + 2RLsin\theta} - R$$

$$= R\left[\left(1 + \frac{L^2}{R^2} + \frac{2L}{R}sin\theta\right)^{\frac{1}{2}} - 1\right]$$

$$c\tau_6 = R\left[\left(1 + \frac{L^2}{R^2} - \frac{2L}{R}sin\theta\right)^{\frac{1}{2}} - 1\right].$$

We can use taylor expansion to time-delay by substituting $x = \frac{L^2}{R^2} + \frac{2L}{R}sin\theta$. Time-delay is replaced with following equations.

$$c\tau_1 \cong Lsin\theta + \frac{L^2}{2R}cos^2\theta$$

$$c\tau_6 \cong -Lsin\theta + \frac{L^2}{2R}cos^2\theta$$

The range of underwater source can be obtained by solving simultaneous equation.

$$R = \frac{L^2 cos^2\theta}{c(\tau_1 + \tau_6)}$$

The range is shown as below equation. Delay τ_1, τ_6 are replacement with time-delay ε_{12}, ε_{56} at closely-spaced hydrophone pairs.

$$R = \frac{L^2 cos^2\theta}{c(\tau_2 + \tau_5) + c(\varepsilon_{12} - \varepsilon_{56})}$$

$$R = \frac{(L-d)^2 cos^2\theta}{c(\tau_2 + \tau_5)}$$

Finally, like below equations, underwater acoustic source location can be written

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

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

3. Simulation

The validity of the array is confirmed through the simulation which is use the acoustic signal synthesized by eigenray. The range R is $1\,km$ and the bearing is 0° ~ 45°. The signal-to-noise ratio(SNR) is 10dB ~ 20dB. Widely-spaced hydrophone distance is 20m. Closely-spaced hydrophone distance is 1m. Following figures are result of monte-calro simulation. Time-delay of the closely-spaced hydrophone pair is obtainable from cross-correlation.

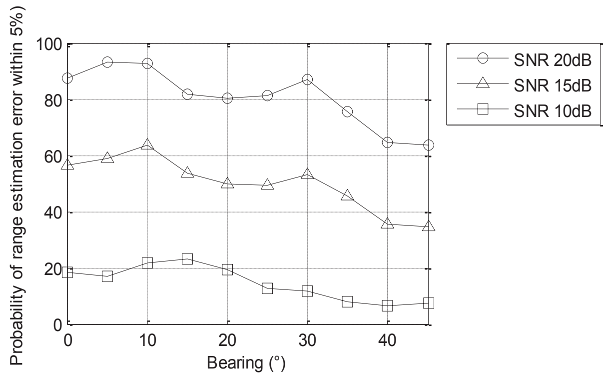

Fig. 2 Range estimation(probability VS bearing)

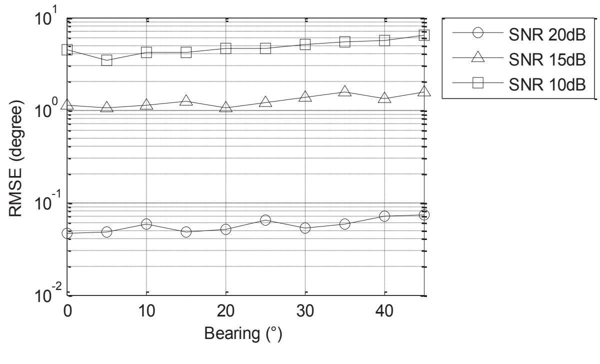

Fig. 3 Bearing estimation(RMSE VS bearing)

In **Fig. 2**, the better probability of range estimation is, the smaller bearing is. Because range resolution is good when the array aperture is long. In **Fig. 3**, the bearing estimation performance is steady. The synthesized signal used for simulation that is include multi-path environment. But performance degradation is not occur in target localization. **Fig. 4**, is result of single-path and multi-path simulation on SNR = 20dB.

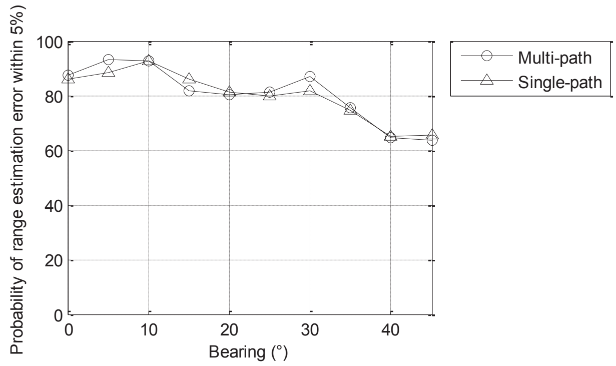

Fig. 4 Range estimation(multi-path VS single-path)

4. Conclustion

We propose closely-spaced hydrophone pairs array to find the underwater acoustic source location using time-delay at hydrophone pair. We derive the equation that is described as time-delay at closely-spaced hydrophone pair. There is no performance degradation when signal has multi-path delay. Through the simulation, highly efficient array is verified. For rigorous verification, far-/near- field conditions should be considered.

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