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A Study of Vertical Sound Profiler Using Doppler Shift at Flow Field

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1. Introduction

Vertical sound speed profile (SSP) is one of the important parameters for SONAR operation and some equipment using sound as a sensing device. As the sound speed in the ocean is determined by its temperature, pressure, and salinity, sound speed is often calculated from those parameters rather than directly measured. Expendable bathy thermograph (XBT) and expendable conductivity temperature and depth meter (XCTD) are mainly used to quickly obtain those parameters as they are symple and disposable methods. As XBT is cheaper than XCTD, XBT is maily casted but it cannot measure salinity. Therefore, statistical salinity is used to calculate sound velocity. If there are some different salinity structure, the estimated SSP must be different from the real value. To avoid these risk, it is necessory to get SSP more simple and resonable way.

Authors suggest a new SSP measurement method using Doppler shift and succeed to obtain SSP in a tank experiment. In the experiment, all equipment set in one line, and there were no current existing like real ocean. To apply this method into the real ocean,

2. Theory

2.1 Doppler shift in one dimension

Here, we consider the Doppler shift between moving transducer with speed v_s and moving reflector with speed v_t. In the conventional Doppler shift equation, only the sound velocity near the transducer c_s is considered. But Tanaka et al. considered the sound velocity near the reflector c_t and derived

$$\Delta f = 2\left(\frac{v_s}{c_s} - \frac{v_t}{c_t}\right) f \qquad (1)$$

as a new Doppler shift equation[1]. Eq.1 is obtained from Taylor-expanded and approximated by omitting the second and subsequent terms of

$$f' = \frac{c_s - u_s + v_s}{c_s - u_s} \cdot \frac{c_t - u_t}{c_t - u_t + v_t} \cdot \frac{c_t + u_t - v_t}{c_t + u_t} \cdot \frac{c_s + u_s}{c_s + u_s - v_s} \cdot f \qquad (2)$$

where, f' is received frequency, u_s and u_t is flow speed of source moving direction near the source and target, respectively.

In our measurement method, we measure sound frequency from moving source with known speed at the fixed receiver. Therefore, Doppler shift occurred only at the moment of the sound transmitted from the source which explained at the fourth term in Eq. 2. Assume that the current flow is perpendicular to the source moving direction which means $u_s = 0$, sound speed around the source cs can be obtained from

$$\Delta f = \frac{-v_s}{c_s + v_s} \cdot f. \qquad (3)$$

Using this equation, we can obtain sound velocity near the moving object, which is far from transducer. In this study, authors envision a new system which has a fixed receiver on shipboard, and a sound source falling down into water. If the transmitted signal is known, the Doppler shift amount can be calculated from the received waveform. If the source falling speed is known, we can get sound velocity near the falling source using Eq.3.

2.2 Doppler shift in two dimensions

At the real ocean, water always move by current, surface wave and other moving objects. When the measurement equipment drops into the water, its movement changes according to the gravity, buoyancy and flow in the water. To consider the flow effect, we expand the measurement system in two dimensions. In this system, four fixed receivers are located at the position shown in **Table 1**. Set the sound speed c as

$$c = 1500 - 0.5d \qquad (4)$$

where, d is depth from the surface. Suppose a constant horizontal velocity flow exists in the measurement area. The source drop from the origin of the coordinate moves the source speed v_s and flow speed u_s. Let the position of the source at time t is S_t as shown in **Fig.1**. The sound from source is reflected according to the sound speed gradient and arrive to the receiver with angle $\theta_{34} + \alpha$, where θ_{34} is the angle between the line of R_3R_4, and S_tR_3. The apparent source position at time t is S_t'. From the angle toward the array R_3R_4 and R_1R_2, the apparent source position $S_t'(X_t', Y_t')$ is estimated. As falling

Table 1 Coordination of the source and receivers.

Object	Symbol	Coordinate (m)
Receiver 1	R_1	(75, 0)
Receiver 2	R_1	(70, -5)
Receiver 3	R_1	(-75, 0)
Receiver 4	R_1	(-70, -5)
Initial Source position	S_0	(0, 0)

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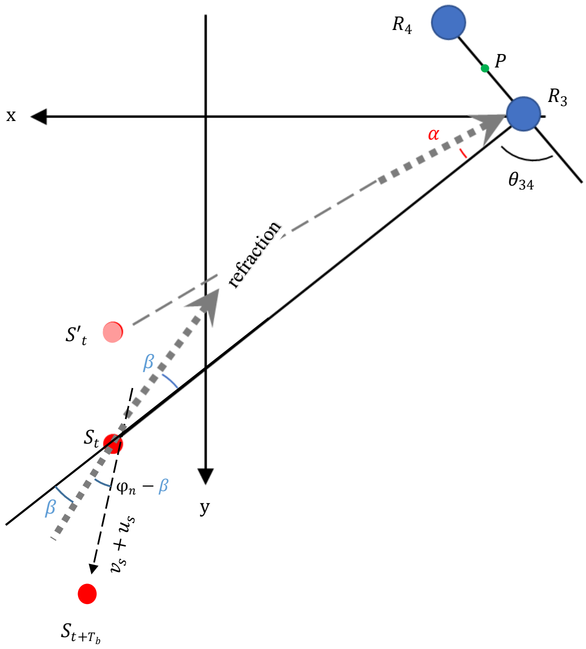

Fig. 1 Coordinate of arrays and the sound source.

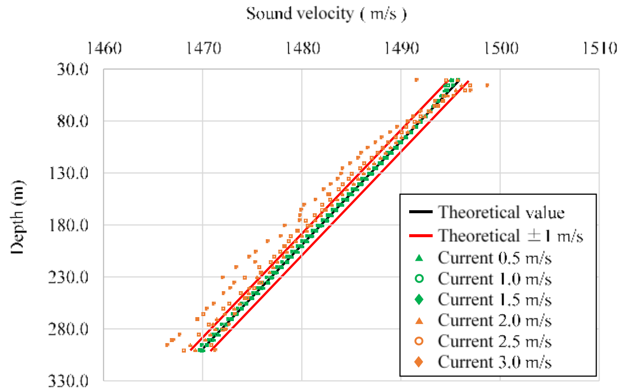

Fig. 2 Estimated sound speed by simulation under the different flow speed.

speed v_s is known, y-axis coordination of the source at t is v_s t. Since flow speed u_s is unknown, we use estimated X_t'as x-axis coordination and get $S_t(X_t', v_s t)$. As SSP has liner gradient, the trajectory of the sound is a part of arc[6]. Therefore, the radiation angle $\beta = \alpha$. The Doppler shift effects only the component of ray direction of vector $v_s + u_s$. Suppose $\varphi_n$is the angle between the line S_tR_3 and vector $v_s + u_s$, v_s in Eq. 3 is replaced by $|v_s + u_s|\cos(\varphi_n - \beta)$.

3. Simulation and Result

For the calculation, the source speed $v_s = 5$ m/s and flow speed u_s varied from 0.5 m/s to 3 m/s with 0.5 m/s range. From the source position, 20Hz burst sinusoidal sound wave generated and calculate the wave form at the four receivers. From the calculated wave forms and elapsed time, source position S_t was estimated and aimed the sound speed at the source from Eq.3. The simulation was carried out in the range of depth from 40 m to 300 m. Since the wavefront is treated as a plain wave, the approximation in short distance between the source and the receiver is hard.

The results show in **Fig. 2**. Under the flow speed up to 1.5 m/s, the estimated sound speed is within the 1 m/s range of the theoretical value.

4. Conclusion

We present a new method for SSP in the ocean using Doppler shift and apply this method in the condition with constant horizontal flow and linear sound speed gradient exist. The calculated results shows that this method can measure sound speed with an accuracy of ± 1 m/s under flow speed below 1.5 m/s.

In this simulation, the SSP assume to change only in linear. To apply into the real ocean, it is required to modify any SSP changes. Furthermore, as the receivers supposed to locate on the observation ship, the Doppler shift from the receivers movements also have to include for more real measurement conditions.

References

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