The Application of Single Vector Sensor in Direction Tracing of Water-entry Object

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Key words: Azimuth Estimation，Vector Sensor，Direction Tracing，Water-entry Signal

Abstract. Water-entry signal was important to broadcast the water-entry object. The vector sensor could gain the pressure and particle velocity signal, so the azimuth angle of water-entry signal could be estimated by single vector sensor. The complex sound intensity method was applied in vector signal processing in azimuth estimation. The estimated deviation in different SNR was give out via simulating experiment. The method was used in the experiment on the lake and was proved to be effective.

Introduction

In order to broadcast the water-entry object, the azimuth angle was an important information of water-entry signal. Here the advantages of vector sensor was obvious.

The pressure and the velocity information of the acoustic field at the same point could be gained by a single vector sensor at one time. There was no directional ability in the pressure information. When the direction of the signal source would be estimated, an ordinary hydrophone array composed with several hydrophones was needed. The underwater acoustic signal could be transmitted for a long distance only when it was on the low frequency period, when an even larger array was needed. In order to solve this problem, more information was required. As the theory of the vector sensor was developing, the particle velocity of could be measured and this velocity information implied directional ability. Thus only one vector sensor was needed to estimate the direction of the acoustic source.There were several advantages of vector sensor: 1. Gain more information and provides more space in data processing; 2. Dipole directionality which was independent with the frequency; 3. No indistinct of right and left side; 4. Strong anti-interruption ability of isotropy background noise; 5. Less weight, smaller size leads to easier arrangement.There were two algorithms with the single vector sensor in estimating the direction: Complex intensity of sound method and Eigenvalue of particle velocity method.

Summary of Theory

There was no obviously distortion in the sound field when measuring with a co-vibrating vector sensor, and its characteristic parameters were all stable, so it was used normally in practice. The outputs of a co-vibrating vector sensor were the sound pressure p , and the velocities v_x, v_y, v_z of the particle on the orthogonal three dimensions x, y, z . The particle velocities information on the three directions could compose a unit vector as shown in Eq. (1) below:

$$n = [\cos\phi\cos\theta, \sin\phi\cos\theta, \sin\theta] \tag{1}$$

When the wave impedance of plane wave was supposed to be $\rho c = 1$, the measurement formula of the vector sensor could be shown as the Eq. (2).

$$\begin{cases} p = x(t) \\ v_x = x(t)\cdot\cos\phi\cos\theta \\ v_y = x(t)\cdot\sin\phi\cos\theta \\ v_z = x(t)\cdot\sin\theta \end{cases} \tag{2}$$

Where $x(t)$ was the time domain wave of pressure signal, ϕ was the horizontal azimuth, and θ was the elevation angle.

Complex intensity of sound method was a cross-spectrum processor of sound pressure and particle velocity. Its amount of calculation was more than the mean-intensity of sound method. But there were several advantages in detecting, direction estimating and multi-target resolving. So the complex intensity of sound method was used in practice usually. The block diagram of complex sound intensity method was shown in Fig. 1 as below:

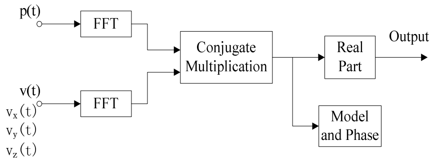

Fig. 1 The block diagram of complex sound intensity method

According to the basic characteristics of the Fourier Transformation, the most energy of two signals which were input with the same phase was focus on the real part of the cross-spectrum. So the energy of target signal was focus on the real part of the cross-spectrum, and the image part was mainly about the energy of interference signal. Then the horizontal azimuth of the target source could be estimated through the Eq. (3).

$$\hat{\phi}(w) = \arctan\left[\frac{I_{Ry}(w)}{I_{Rx}(w)}\right] = \arctan\left[\frac{\mathrm{Re}[I_y(w)]}{\mathrm{Re}[I_x(w)]}\right] = \arctan\left[\frac{\mathrm{Re}[P(w)V_y^*(w)]}{\mathrm{Re}[P(w)V_x^*(w)]}\right] \tag{3}$$

The horizontal azimuth $\hat{\phi}(w)$ was zero on the axis x, and it was increased through rotating anticlockwise. The water-entry signal was usually occurred on the surface of water, so the elevation angle was ignored at most of time. And it was not discussed here either.

Simulation

In order to improve the theory of azimuth angle estimation on signal vector sensor and apply it in the practice measuring, the simulating experiment was carried out. In this experiment The simulating signal was composed of a single frequence cosine signal and noise. The noise added was a gauss white noise. Here the frequence of the signal was f_0=100Hz, and the simple frequence was f_s=1024Hz. The target azimuth angle was configured to be -90 degree and the phase difference between the x axis and y axis was supposed to be zero.

To discuss the effect of the theory proposed above on different SNR, the deviation on different SNR simulation was carried out. The SNR was valued from -10dB to 40dB. The result was put out in Fig.2 below.

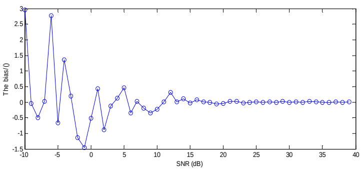

Fig. 2 The estimation deviation on different SNR

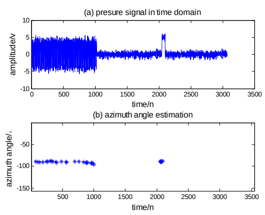

Fig. 3 The azimuth angle estimation of simulating signal

From Fig.2, it was clearly that the complex sound intensity method in azimuth angle estimation was unbiased when the SNR was larger than 15dB.

Considering the result of Fig.2, the simulating signal was configured as: the SNR=15dB, the signal frequence was f_0=100Hz, and the simple frequence was f_s=1024Hz, The target azimuth angle was -90 degree and the phase difference between the x axis and y axis was supposed to be zero. The water-entry signal was predigested as a pulse which width was 50 points. And the added noise was gauss white.

In order to estimate the azimuth angle at some time, the time domain signal was divided into several segments. The complex sound intensity theory was applied in each segment to calculate an azimuth angle. The segment was divided by a sliding window. Here the width of the window was 100 points and the sliding step was 10 points.

The simulating experiment was carried out in a computer and the azimuth angle estimation result was shown in Fig.3.There were two drafts in Fig.3. Draft (a) was the pressure signal in time domain. In the beginning part of draft (a) was a single frequence signal which was corresponding to the motorboat engine signal. In the middle part was a zero zone, where the motorboat engine was put out. The third part was a pulse which was supposed to be the water-entry signal of the dropped object. Note about that, this signal would be more complex in practice. Here was only a simplified water-entry signal. Draft (a) was a time reference here. Draft (b) of Fig.3 was the azimuth angle estimation. From the configuration of the simulation given above, the azimuth angle was -90 degree. And it was inosculated with draft (b). Here the point appeared near 2000 time point was the water-entry pulse azimuth angle.

As the result of Fig.3, a single vector sensor could provide the azimuth information in broadcasting and tracing a water-entry object.

Experiment

The simulation of the single vector sensor used in azimuth estimation of water-entry signal was carried out and proved that the method was effective. So it was applied in a practice experiment which was taken out on a lake.

Firstly, the arrangement of the measurement system was connected as shown in Fig.4. Here the vector hydrophone was a co-vibrating vector sensor. The processed signal was measured by it. And the standard hydrophone was a common pressure sensor which was used only as a reference.

The instruments connection in the experiment was shown in Fig.5. Here the function of Date Acquisition Unit (DAU) was to gain the signals measured from the hydrophones and transport them to a personal computer where the signal could be processed. In this experiment, the sampling frequence of the DAU was f_s=100k.

After the spectrum analysis, the frequence of motorboat was in the low frequence period and the energy of water-entry pulse was also focused on the low frequence segment. So the signal from DAU could be de-sampled to simplify the calculation. Here the sampling frequence could be decreased to f_s=10k.

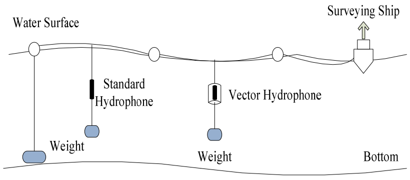

Fig. 4 The arrangement of the measurement system

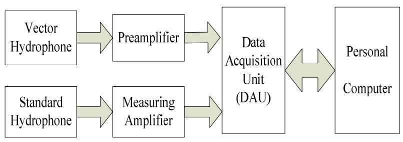

Fig. 5 The instruments connection in the experiment

As the simulation, a sliding window was needed. The width of the window was 1000 points and the sliding step was 10 points. In order to prove the method was useful on a common occasion, several instances were given out in Fig.6.

(1) big model water-entry position azimuth estimation (2) small model water-entry position azimuth estimation

Fig. 6 The azimuth angle estimation in the experiment

Compared to Fig.3, drafts in Fig.6 were proved that the method was also effective in practice.

Conclusion

The vector sensor could not only measure the intensity of the sound pressure but also measure the particle velocities. That's to say, a single vector sensor which was used in measuring a water-entry signal could give out azimuth information at the same time with the energy and intensity information. This function was very important in broadcasting, detecting, and tracing a water-entry object.

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Published by Atlantis Press, Paris, France.