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Method Based on the Application of Single Vector Handset in Ocean Engineering

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Abstract: Vector hydrophone has high sensitivity and good directivity, small size, low cost advantages, in the complex underwater acoustic environment has a good anti-jamming ability, in terms of location, orientation, and signal processing achieved fairly good results, and the vector hydrophone has been successfully applied to the underwater navigation and positioning and underwater target detection, etc. In this paper, the method based on the application of single vector handset in ocean engineering is studied. In this paper, vector hydrophone is applied to ocean engineering, an underwater platform model is established, a set of data acquisition software is written, and an acoustic vector system is built for lake test. The results of experimental data processing verify the correctness and effectiveness of the research method in this paper.

1. Introduction

The vast majority of the earth is covered by oceans, but our understanding and use of the oceans is very limited. China has a coastline of more than 18,000 kilometers, with rich Marine resources. In addition, in recent years, there have been frequent underwater vehicle invasion events in the surrounding waters, and the state has paid more and more attention to the monitoring and protection of the safety of Marine resources and environment [1-2]. Meanwhile, in order to promote the original innovation of Marine science and technology in China, the National Natural Science Foundation of China has carried out the "Shared voyage Plan of Marine scientific research vessels" for many years. In the aspect of ocean exploration technology, the main technical means at present include underwater acoustics, optical exploration, electromagnetic technology and magnetic induction communication technology. Each technology has its own inherent advantages. In terms of detection range, hydroacoustics can detect information from a few kilometers away, while the other three ocean detection technologies have a detection range of less than 100 meters, and electromagnetic technology has a communication range of less than 10 meters. For the vast ocean, underwater acoustic detection technology has more advantages [3-4]. Hydrophone is an important basic equipment to acquire underwater acoustic signal. The processing technology of underwater acoustic signal is of great significance to the engineering application of underwater acoustic detection. Underwater acoustic detection is not only of great strategic significance to China's Marine security, but also of great importance to safeguarding the national economy and people's livelihood [5-6].

For a long time, people have acquired underwater acoustic information through sound pressure hydrophones, and the physical sound field information obtained is single, which cannot comprehensively analyze the characteristics of target acoustic signals [7]. The emergence of vector hydrophones has greatly improved people's ability to detect the ocean. The vector hydrophone can synchronously pick up the sound pressure and particle vibration velocity information in the sound field information at the same point in space, so as to realize the non-fuzzy orientation of sound source in space [8]. Abroad to carry out the development of the vector hydrophone work earlier, the United States naval ordnance laboratory in the 1960 s to create a performance of vector hydrophone, mature and uniform rigid sphere movement in the underwater acoustic field was deduced the mathematical expression of its perfect work presented a scientific workers' enthusiasm for research and development of vector hydrophone [9]. The internal elements of the hydrophone are based on inertial sensors and are suspended and supported by elastic elements, generally rubber ropes or metal springs, which perceive the sound field vector information through the motion of the hydrophone itself in the underwater sound field [10]. With the continuous progress of micro-electrical system (MEMS) technology, MEMS has been widely concerned by all walks of life because of its small structure size, excellent performance and mature technology, which can meet the requirements of multifunctional integrated production [11-12]. Research and development of vector hydrophone is no exception. Chinese scientists have put a great deal of effort into MEMS vector hydrophone.

Signal denoising as an important technique of signal preprocessing is worth further exploration. In the application of vehicle intrusion monitoring, oil and gas pipeline leakage detection, ship safety and other aspects, we all need to conduct directional positioning processing of the signals generated by the monitoring target. Because of the wide application range, this technology has always been a hot topic of the research of the vast number of scientific researchers.

2. Single Vector Hydrophone Application

2.1. How Vector Hydrophones Work

As a multidisciplinary interdisciplinary, bionics links biological systems with engineering design and plays an important role in various fields [13]. The development of bionics provides reference for the design of sensors, understanding the principles and functions of biological systems, and providing models for the realization of specific design purposes. Some of the problems in engineering technology can be learned from nature. After millions of years of species selection and continuous evolution, organisms have optimized their own performance to the extreme, which has reference value in information exchange, energy transformation and environmental adaptation, and can be effectively applied in industrial production and engineering technology design [14-15].

The lateral line is the unique auditory organ of fish and amphibians, which enables them to accurately acquire external information even in a light-free environment. External signals generate pressure changes in the water, pressure acts on the sensory apex, causing deformation of the sensory apex, and deformation is transmitted to the movable cilia through internal mucus. The wiggling of motile cilia results in the stimulation of sensory cells, which is transported by nerve fibers to the medulla of fish, so that fish can obtain external information [16-17].

Inspired by the lateral line of fish in nature, the designed ciliated hydrophone can effectively realize the recognition and orientation of underwater acoustic targets. The sensitive structure of hydrophone is composed of silicon micro cross beam chip and bionic cilia processed by MEMS technology. Similar to the perception of signals by the lateral line system, sound waves are transmitted to the acoustic cap of the hydrophone, causing the cap to deform and act on the bionic cilia through the silicone oil inside. The swing of the bionic cilia drives the silicon micro-cross beam chip rigidly connected with it to deform [18].

The sensitive structure of MEMS hydrophone can pick up the underwater acoustic signal mainly by the same vibration of cilia and liquid particles. The model of biomimetic cilia receiving acoustic signals is established, as shown in FIG. 1. Biomimetic cilia are rigid cylinders. When acoustic waves act on the hydrophone, the acquisition of underwater acoustic signals by biomimetic cilia can be regarded as a scattering problem of cylinders in underwater acoustic fields. Due to the scattering effect, the cilia are under the joint action of free field and scattered wave sound pressure.

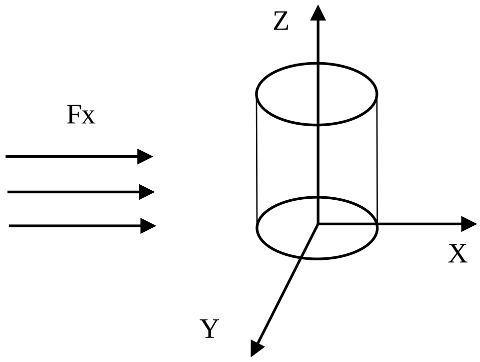

Figure 1. Ciliary acoustic scattering pattern

When a plane wave in the X direction acts on the biomimetic cilia, the sound pressure is P (X,t)=p0ej(wT-kx), and the vibration velocity VC of the biomimetic cilia can be expressed as follows.

$$v_x = \frac{F_x}{Z_m + Z_s} \tag{1}$$

Among them, Fx is the force received by the biomimetic cilia under the action of sound waves, Zm is the mechanical impedance of the cilia, and Zs is the radiation impedance received by the biomimetic cilia.

$$\frac{v_x}{v_0} = \frac{4}{j(ka)^2 \pi \frac{\bar{\rho}}{\rho_0} \frac{dH_1^{(2)}(ka)}{d(ka)} + \pi (ka) H_1^{(2)}(ka)} \tag{2}$$

$$|\frac{v}{v_0}| = \frac{2\rho_0}{\rho_0 + \bar{\rho}} \tag{3}$$

Where V is the vibration velocity of the cilia, and v0 is the vibration velocity of the medium particle at the position of the cilia. P is the density of cilia, P 0 is the density of medium. According to Equation 3, when the density of the bionic cilia is equal to the density of the medium, the vibration velocity of the bionic cilia is the same as that of the particle at its location, and the phase difference between the bionic cilia and the particle is close to zero, which can make it effectively pick up sound signals. The material attributes are shown in Table 1.

Table 1. Biomimetic cilia and material properties of silicon

Material	Density(kg/m^3)	Modulus of elasticity(PA)	Poisson's ratio
Silicon	2330	1.7×10^{11}	0.27
Polyethylene	1046	6.4×10^{7}	0.41

2.2. Design of Vector Signal Conditioning Circuit

(1) Amplifier circuit design

In this design, an ultra-low noise instrument amplifier AD8429 is selected. The device can measure the small signal stably at the temperature of -400℃ ~ +1250℃, can reliably amplify the rapidly changing signal, and provide high bandwidth in the case of high gain. It also has excellent distortion characteristics, which can be used in vibration analysis and other harsh conditions. Fully meet the requirements of hydrophone application environment. The amplifier is also used in medical instruments, precision data acquisition systems and microphone preamplifiers.

When designing amplifying circuit part, by the former stage amplifier should be fully considered part of the introduction of noise, because the hydrophone structure for MEMS technology manufacturing and become, is difficult to ensure that each bridge in ion implantation on the resistance of the resistance is the same, so the actual finished product structure on the bridge resistance tolerance more or less, this leads to when energized bridge, In the absence of external forces, the bridge is also in an unbalanced state, and a voltage output will be generated when static. To eliminate this DC signal, a capacitor can be added at the front or back end of the amplifier to eliminate this DC signal in the form of AC coupling between the microstructure and the amplifier or the amplifier and the back-end circuit. Considering the characteristics of the instrument amplifier itself, the input bias current must have a return path to the ground, otherwise the amplifier will be saturated and unable to work. After calculation and actual measurement, the input voltage of the amplifier is set as plus or minus 5V, and the gain of the amplifier is set as 300 times. In order to reduce circuit noise during PCB layout, a 0.1uF capacitor is connected to the power supply pin of the amplifier to provide a low impedance path for high-frequency noise generated by the power supply and the amplifier to introduce the noise into the stratum. Grounding of the bypass capacitor often produces some parasitic inductors that adversely affect the low impedance of the bypass capacitor. Therefore, a 10uF capacitor is connected in parallel next to the 0.1uF capacitor.

(2) Filter circuit design

With MEMS technology ion implantation not consistent and led to a wheatstone bridge in static state will have the signal output, due to its do not change we can view it as a dc signal, the sensor differential signal is connected to the instrumentation amplifier circuit, series a capacitance in the advantage of the characteristics of capacitance on ac dc resistance will be the dc signal filtering. Since the instrument amplifier needs to have a return path to earth, we add two resistors to earth after the straight capacitance in the design of the circuit. At this time, the combined network of capacitance and resistance just constitutes a passive high-pass filter circuit.

In the selection of capacitance resistance, we should fully consider its influence on the amplifier and the noise of the whole circuit, because the RC high-pass filter circuit before the amplifier circuit, so the resistance value should be as small as possible, too large resistance will produce thermal noise to increase the noise of the whole circuit. The cut-off frequency of the high-pass filter is set to 4.8 Hz, which meets the bandwidth requirements of the hydrophone. On the basis of the previous high-pass filter, a low-pass filter is needed to form a band-pass filter, whose passband frequency is consistent with the bandwidth of the hydrophone.

(3) Matching circuit design

Since the hydrophone needs to be output through a long cable in application, the signal will be reflected in the cable due to the change of transmission line impedance during signal transmission, and the output signal will generate noise signal with large amplitude. Therefore, a matching resistor should be connected in series between the signal output and the cable. As mentioned in the above section, the operational amplifier used for filtering is a double op-amp structure, and one op-amp is used in the design of the low-pass filter. Another op-amp terminally connects it to form a voltage-following circuit, allowing it to adjust the impedance and isolate the front and rear stages of the signal. The empirical value of cable impedance is 50 ohms.

3. Experimental System Construction and Data Processing

The sensing equipment of the experimental system consists of a two-dimensional vector hydrophone, a depth sensor and an attitude meter, which need to be collected and stored synchronously in real time. The system information collected is shown in the following table:

Table 2. Some device information

Device name	Model	Data interface	Power supply voltage
Packaged type controller	cRIO-9031	Link	9-39v
Conditioning the I/O module	NI-9239	BNC	
Depth sensor	PTX-1830	RS-485	24v
Attitude indicator	HMR-3500	RS-232	5v

Using LabView software to realize the programming development of acquisition equipment, underwater acoustic vector monitoring system real-time data acquisition software is for real-time acquisition of vector sensor signals, for real-time information processing, detection of surface and underwater targets.

The basic control process of the collection device is as follows:

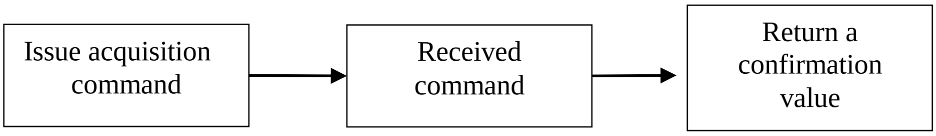

Figure 2. Basic control flowchart of the collector

After starting data collection, the generated one-dimensional array obtains data every 0.5s. The data packet contains the data of 8 channels of the collector. On the one hand, the channel data that is being observed in real time is taken out, and on the other hand, the data is stored and processed. When the controller sends the command to stop collection, the collector stops work to complete data collection.

4. Analysis of Experimental Results

As shown in Figure 3, the SNR gain before and after processing is given, which is more than 10dB gain compared with the original data, proving the effectiveness of the system in practical application.

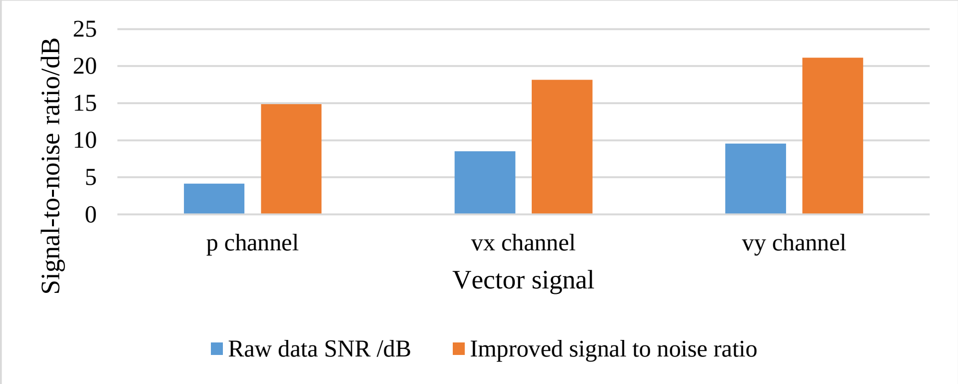

Figure 3. Comparison before and after noise suppression

5. Conclusion

When the vector hydrophone is applied to an underwater platform, the influence of ocean background noise and some near-field noise sources will greatly interfere with the signal reception of the vector hydrophone, resulting in poor bearing estimation performance or even failure. Aiming at the application of vector hydrophone on underwater platform, the measurement model of single vector hydrophone is established, and the spatial correlation function between the sound pressure of vector hydrophone and particle vibration velocity is deduced. Taking the background noise field of Marine environment as the research object, a typical spatial model was established from the perspective of vector characteristics, and the vector characteristics and spatial distribution characteristics of the sound field of Marine environment were studied. The underwater platform model is established, and the background noise and platform interference are suppressed by using the directivity of the vector hydrophone, which improves the SNR gain and azimuth estimation accuracy. Finally, the lake test data are processed to verify the correctness of the theory and method studied.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

References

[1] Saheban H , Kordrostami Z , Hamedi S . A multi-objective optimization of sensitivity and bandwidth of a 3-D MEMS bionic vector hydrophone. Analog Integrated Circuits and Signal Processing, 2020, 110(3):455-467. https://doi.org/10.1007/s10470-021-01975-z

[2] Kavoosi V , Dehghani M J , Javidan R . Underwater Acoustic Source Positioning by Isotropic and Vector Hydrophone Combination. Journal of Sound and Vibration, 2020, 501(14):116031.

[3] Armstrong B A . A primer on vector hydrophones. The Journal of the Acoustical Society of

America, 2018, 144(3):1916-1916. https://doi.org/10.1121/1.5068392

[4] Kim J , Kim H , Roh Y . Analysis of the beam pattern of a thickness shear mode vibrator for vector hydrophones. The Journal of the Acoustical Society of Korea, 2017, 36(3):158-164. https://doi.org/10.7776/ASK.2017.36.3.158

[5] Morgunov Y N , Bezotvetnykh V V , Burenin A V , et al. An Autonomous Combined Receiving Acoustic System Based on a Three-Component Vector Receiver and a Hydrophone. Instruments and Experimental Techniques, 2019, 62(3):412-415. https://doi.org/10.1134/S0020441219020210

[6] Patel B K , Bahl R , Kumar A . Acoustic source localization accuracy using network of sonobuoys of omni-directional hydrophones and acoustic vector sensors. India Review, 2018, 45(2018):1-15.

[7] Ao Y , Xu K , Wan J , et al. Normal Mode Based MUSIC Method for DOA Estimation in Shallow Water Using a Single Vector Sensor. IOP Conference Series Earth and Environmental Science, 2019, 242(2):022010. https://doi.org/10.1088/1755-1315/242/2/022010

[8] Deal T J , Smith K B . Reciprocity relationships in vector acoustics and their application to vector field calculations. Journal of the Acoustical Society of America, 2017, 142(2):523-529. https://doi.org/10.1121/1.4996458

[9] Nichols B , Martin J , Verlinden C , et al. Enhancing ambient noise correlation processing using vector sensors. The Journal of the Acoustical Society of America, 2019, 145(6):3567-3577. https://doi.org/10.1121/1.5111335

[10] Kim S , Choi J W . Optimal Deployment of Vector Sensor Nodes in Underwater Acoustic Sensor Networks. Sensors, 2019, 19(13):2885. https://doi.org/10.3390/s19132885

[11] Choi K H , Kim H , Choi J W , et al. Vector communication by moving source during KOREX-17. The Journal of the Acoustical Society of America, 2019, 146(4):2764-2764. https://doi.org/10.1121/1.5136571

[12] Deal T J . Passive detection of low frequency sources using vector sensor channel cross correlation. Journal of the Acoustical Society of America, 2017, 141(5):3650-3650. https://doi.org/10.1121/1.4987893

[13] Romashko R , Kulchin Y N , Dzyuba V P , et al. Laser adaptive holographic sonar intensimeter. Quantum Electronics, 2020, 50(5):514-518. https://doi.org/10.1070/QEL17223

[14] Kim J , Yang S , Oh K , et al. A piezoelectric micro-cantilever acoustic vector sensor designed considering fluid–structure interaction. The Journal of the Acoustical Society of America, 2020, 150(1):257-269. https://doi.org/10.1121/10.0005538

[15] Stinco P , Tesei A , Dreo R , et al. Detection of envelope modulation and direction of arrival estimation of multiple noise sources with an acoustic vector sensor. The Journal of the Acoustical Society of America, 2020, 149(3):1596. https://doi.org/10.1121/10.0003628

[16] Sabra K G , Nichols B , Martin J S , et al. Exploiting ambient noise for coherent processing of mobile vector sensor arrays. The Journal of the Acoustical Society of America, 2018, 144(3):1915-1916. https://doi.org/10.1121/1.5068390

[17] Naik M R , Kempaiah U N , Kushal U K . Analysis of MEMS Piezoelectric Hydrophone at High Sensitivity for underwater application. Materials Today Proceedings, 2017, 4(10):10803-10809. https://doi.org/10.1016/j.matpr.2017.08.031

[18] Fuad M , Jali M H , Ghani M , et al. Detection of Aedes Aegypti larvae frequency range using signal processing method. Materials Today: Proceedings, 2019, 16(P4):1894-1900. https://doi.org/10.1016/j.matpr.2019.06.066