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Ultra-Short Baseline Positioning System for Full Ocean Depth

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Abstract

Ultra-Short Baseline Positioning System for Full Ocean Depth is presented in this paper. A planar array is used to complete the intelligent beam tracking for improving signal-to-noise ratio. Spatial spectrum estimation technology is realized for two-dimensional direction of arrival estimation. And the feedback positioning results can be employed to track the target and achieve ultra-long-distance positioning. Quadri-Phase Shift Keying (QPSK) orthogonal separation code is proposed and designed to resist strong noise interference with spikes. The sea trial results show that the maximum detection distance is 15133m and the real-time positioning accuracy is higher than 0.3% of the slant range.

Keywords: Ultra-Short baseline; Full ocean depth; DOA estimation; Efficiency of real-time positioning

Introduction

Underwater acoustic positioning technology is widely used in military and civil fields, such as offshore oil and gas development, deep-sea mineral resources survey, submarine optical cable line survey and maintenance, etc. All these tasks require acoustic positioning system to navigate and locate the underwater carriers. Ultra-Short Baseline (USBL) positioning system is installed on the mother vessel. It receives the acoustic signal from the beacon mounted on the carrier, calculates the beacon's azimuth and distance, and deduces the coordinate position of the underwater beacon. It has the characteristics of low-cost integrated system, simple operation and easy installation. Ultra-Short Baseline positioning system, which can work in the full ocean depth, has not yet been available in any commercial companies. In recent years, the development of underwater submersibles, such as 11,000-meter human occupied vehicle, 11,000-meter underwater remote-control vehicle and autonomous underwater vehicle, has been carried out in some organizations in China. Ultra-Short Baseline Positioning System for Full Ocean Depth needs to be longer ranged, more stable and reliable.

Ultra-Short Baseline Positioning System for Full Ocean Depth announced in this paper was jointly developed by Shanghai Ocean University and Shanghai Goo Hov Electronic CO., LTD and the project was started in 2013. After preliminary design, detailed design, component processing, system commissioning and pool test, two sea trials were successfully carried out in 2017 and 2018, respectively. The experimental results show that the system can achieve the maximum effective positioning distance of 15133m, and the real-time positioning efficiency is as high as 98%.

Ultra-Short Baseline Positioning System for Full Ocean Depth

Acoustic signal, which is received by the traditional four-element or eight-element receiving array [1,2], is very weak after long-distance transmission. It is difficult to achieve accurate positioning solution and brings many false alarm and invalid data, which is intolerable for the safety of personnel and underwater carriers. The advantage of planar array or arc array is that beamforming can improve signal-to-noise ratio and increase operating distance. Although some Ultra-Short Baseline product instructions [3-5] label that the operating distance can reach more than 10,000 meters, there is no practical application precedent and relevant reports of Ultra-Short Baseline positioning beyond 10,000 meters. In this system, a 36-element planar array is used to complete the intelligent beam tracking for improving signal-to-noise ratio. Spatial spectrum estimation technology is realized for two-dimensional direction of arrival estimation. And the feedback positioning results can be used to track the target and achieve ultra-long-distance positioning.

The vessel has three rotating components, i.e. pitch, roll and yaw, which deflect along three coordinate axes. Due to the fluctuation characteristics of sea water, the instantaneous attitude of the mother vessel is continuously changing. Attitude sensors need to be connected to stabilize the received beam in real time. No matter how the vessel sways, the beam steering always points to the direction of the incoming wave. The traditional USBL system uses external sensors. The installation position of the USBL transducer is different from that of the attitude sensor. There is an angle deviation between the base plane of the attitude sensor and the plane of the USBL sonar array. This angle deviation will affect the accuracy of direction finding. It usually needs many complex calibration tests at sea to determine this angle deviation. The system adopts the integrated installation mode, encapsulates the fiber-optic inertial navigation system and USBL in the underwater sonar cabin. The deviation between the base plane of attitude sensor and the plane of USBL sonar array is fixed. It only needs one calibration (which can be completed in the pool or lake). The calibration results are provided to the users as the factory parameters of the equipment, and the calibration experiments are not necessary for each installation. This greatly simplifies the sea trials.

In the course of vessel navigation, strong noise interference often occurs in propellers, seawater pumps and air conditioning compressors. False alarm will still occur even if spread spectrum processing is carried out. This requires that the circuit design and communication coding design of USBL system have strong anti-interference ability. This system proposes and designs spread spectrum communication based on Quadri-Phase Shift Keying (QPSK) orthogonal separation code. It consists of multiple pseudo-random sequences. Through multiple de-spreading processing of signals, a specific set of characteristics can be obtained in time domain. By detecting and recognizing this feature, interference can be effectively eliminated, and useful signals can be retained. The experimental results show that this method can still obtain effective positioning results in acoustic noise environment with spikes.

As shown in Figure 1, Ultra-Short Baseline Positioning System for Full Ocean Depth consists of dry part and hull unit. The hull unit includes hydrophone array, electronic module and fiber-optic inertial navigation system. The hull unit is mounted on a gate valve and can reach several meters below the water. It is connected to the deck unit on the water by cable. The dry part includes deck unit, UPS uninterrupted power supply and display and control computer.

The hydrophone array is a 36-element planar array, which can receive the acoustic signals sent by the underwater beacon and convert them into electrical signals. The electronic module includes amplifying circuit, data acquisition circuit and signal processing unit. After the signal is amplified and filtered by signal conditioning circuit, the signal is converted into digital signal by data acquisition circuit. The signal processing unit realizes attitude stabilization, beamforming and DOA estimation based on the real-time attitude data accessed by INS, then completes ranging and angle calculations, and finally obtains the geodetic coordinates of the target through sound velocity correction. The deck unit provides power supply and synchronization for underwater sonar cabin and has Interface for external attitude sensor and external GPS. The water surface display and control computer provide user interface, executes system instructions, sets working parameters, acquires and displays processing results.

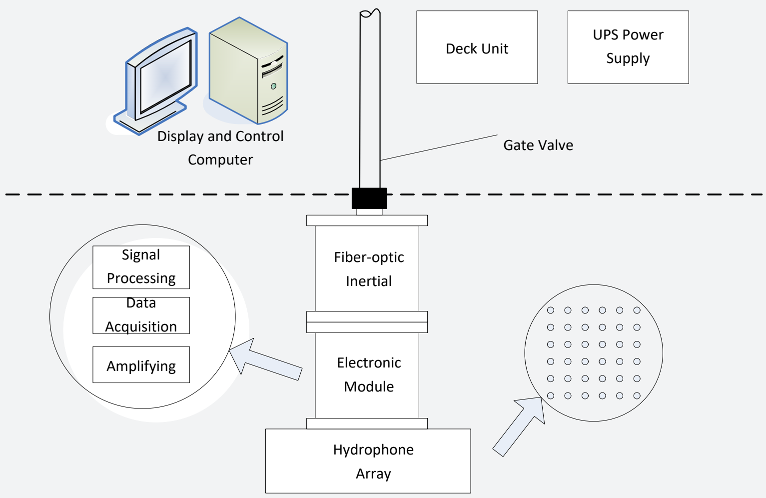

Figure 1: Ultra-Short Base Line Positioning System.

Sea Trial Results

In May 2017, the first phase of sea trial was carried out by the Ultra-Short Baseline Positioning System for Full Ocean Depth on the 'ZhangJian Ship'. During the sea trial, the beacon was installed on top of the lander and dived to the bottom of the sea. The USBL system tracks the lander's descending, bottoming and ascending phases. The lander's bottoming depth is 1829m. The system deviation is obtained by calibration tests of 8-shaped, circular and cross lines. The maximum detection distance of the system is 6000m for the depth of 2000m. The real-time positioning data points are shown in Figure 2. The real-time positioning results are all effective, and the data efficiency is 100%.

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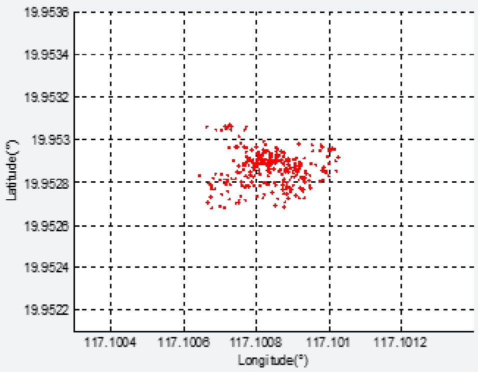

Figure 2: Sea trial bottom target points.

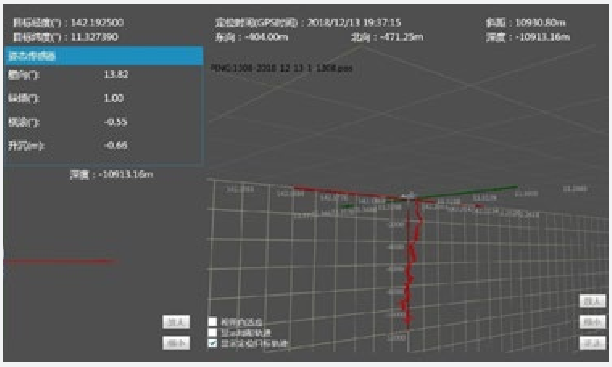

Figure 3: Real-time positioning on display control interface.

Figure 4: The display and control interface showing the sea trial site over Mariana Trench.

In December 2018, the Ultra-Short Baseline Positioning System was carried by 'Shen Kuo' ship to the Mariana trench to implement sea trials at 6,000m depth and 11,000m depth to verify the full-ocean depth coverage functions and maximum effective distance of the system. The test device of the sea trail site is shown in Figure 3 In this sea trial, the coordinates of beacons with depth exceeding 10,000 meters are given for the first time by using the ultra-short baseline system. The beacon's bottom position is 11°19.648'N, 142°11.541'E, and 10,913 meters deep. The display and control interface are shown in Figure 4. The positioning points at the bottom are shown in Figure 5. The real-time positioning accuracy is higher than 0.3% of the slant range. The maximum detection distance of the system is 15133m, and the efficiency of real-time positioning is 98%.

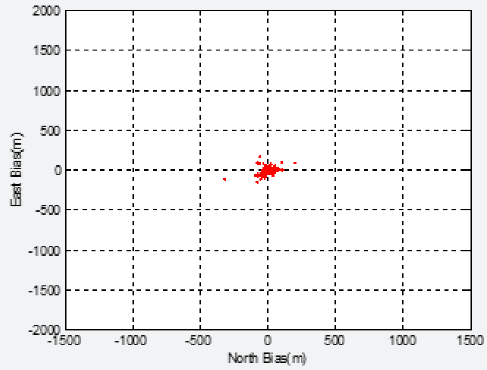

Figure 5: Positioning result of sea bottom.

Summary and Conclusion

Through four years of development and two sea trials, the function and performance of the Ultra-Short Baseline Positioning System for Full Ocean Depth have been fully verified. The system can acquire the accurate coordinates in real time, the maximum detection distance is 15133m, the real-time positioning accuracy is higher than 0.3% of the slant range, and the efficiency of real-time positioning results is 98%. The successful development of this underwater acoustic positioning system clears a technical obstacle for the development of 10,000-meter underwater vehicles and is also a breakthrough in the direction of deep-sea positioning technology.

Acknowledgement

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