Detection Method for Single-Beam Echo Sounder Based on Equivalent Measurement

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Abstract Acoustic instruments like the single-beam echo sounder are basic tools for marine scientific research; consequently, the effective detection and calibration of the equipment are crucial to ensure the quality of marine data. Considering that the detection of full-range precision index of a single-beam echo sounder cannot be carried out in a laboratory sink, this paper proposes a new detection method based on equivalent measurement. In an anechoic environment, a circuit is used to simulate the long-distance propagation of the sound wave. The full-range equivalent measurement of the single-beam echo sounder is realized within the limited range of the laboratory sink. Experimental verification proves that the proposed method is feasible and provides a new technical approach for the detection of marine acoustic instruments.

1. Introduction
Measurement is an important indicator of the national core competitiveness. Ocean measurement, which is a crucial measurement field, plays an integral part of the national ocean strategy [1]. Marine acoustic instruments are the basic tools for marine scientific research, but their effectiveness is limited, owing to existing technology. Moreover, they suffer from a lack of effective laboratory verification and calibration methods, all of which significantly affect the reliability and accuracy of marine data. Establishing a standard measurement method for the single-beam echo sounder, which is the most widely used technology in the field of marine topography, is crucial for ensuring the quality and proper management of marine data, as well as for unifying the standards and controlling their quality [2-3].

In recent years, there have been various explorations at home and abroad on the verification methods used for single-beam and multi-beam echo sounders. In 2011, Zhiming Wang and others conducted a comparative test to evaluate the accuracy and performance indicators of the single-beam echo sounder by introducing higher-precision measuring instruments, such as total stations and GPS RTK rover stations in an anechoic water tank. However, owing to the boundary conditions of the anechoic water sink, the detectable range will be limited [4]. In 2011, Hui Zhao and others introduced a simulation verification method for a single-beam echo sounder, which uses an analogue signal generator to adjust the pulse delay method and an analogue echo signal as a sounding echo to display the depth changes, and then compared the setting depth using the measured data. They, however, did not include a transducer in their study, as a result of which they were unable to verify the performance of the sounder; moreover, they were unable to measure the blind area [5]. In 2012, Jun Gao proposed a
A design scheme for the multi-beam echo sounding system. The laser rangefinder (standard) was used in combination with the sounding system to simultaneously measure and record the signals. The least squares principle was used to fit the data to verify instrument accuracy [6]. In 2005, Bjorke put forward a method for the on-site calibration of the multi-beam echo sounder. The accuracy of the equipment was evaluated using the least squares adjustment of the static offset in parameters such as pitch angle. However, owing to the limited understanding of the randomness of observations, this approach may lead to optimistic precision estimation [7].

To detect the precision index within the full range of the single-beam echo sounder in the national ocean measurement unit laboratory sink, a detection method for the single-beam echo sounder, based on the principle of equivalent measurement, is proposed in this paper. The design of the experimental device enables us to construct the equivalent reflection interface of the acoustic signal, and we simulated the propagation process of the acoustic signal at different distances under actual medium conditions using the underwater acoustic response equipment. Moreover, the testing method and the equivalent measurement function of the detection device were tested. The results show that the proposed method can realize the full-range accuracy detection of the single-beam echo sounder within the limited range of the laboratory sink.

2. Detection Principle

2.1. Equivalent Measurement Principle

The single-beam sounder uses a transducer to transmit a short pulsed sound wave vertically. When the pulsed sound wave reaches the seabed, it is reflected and the echo is then received by the transducer. The data regarding the water depth can be then calculated using the sound velocity and acoustic travel time. The principle of equivalent measurement is shown in figure 1.

The formula to calculate the water depth is as follows:

\[ d = c \cdot \left( \frac{t}{2} \right) \]  

where \( c \) is the velocity of sound in the propagation medium and \( t \) is the travel time of the sound wave.

The sonar equation of the sounding process is expressed as follows:

Received signal strength, as shown in the equation (2):

\[ RL = SL - 2TL + TS \]  

Received-signal-to-noise ratio, as shown in the equation (3):

\[ SNR = RL - NL \]

where \( SL \) is the sound source level, \( TL \) is the propagation loss, \( TS \) is the target intensity and \( NL \) is the marine environmental noise level.

In summation, the sound velocity, acoustic travel time, and acoustic propagation loss (including the sea water propagation and seabed reflection losses) are the three important factors in the single-beam echo sounder sounding process.
Based on equation (1) and (2), the concept of equivalent measurement is proposed in this paper; in other words, the full-range equivalent measurements can be realized in a limited-depth range using certain technical means, as shown in figure 1.

Specifically, the single-beam echo sounder transmits the pulsed sound wave in the anechoic environment; when the sound wave meets the interface with the acoustic signal response equipment (the equivalent reflection interface), the response equipment receives the signal completely and does not produce reflection. The response circuit measures the propagation delay and attenuation loss of the signal. Finally, the transmitter of the answering device sends the signal back to the single-beam echo sounder to complete the entire measurement process.

The response circuit that is based on DSP can accurately calculate the propagation time and attenuation loss of the pulsed sound wave emitted by the single-beam echo sounder; it uses the circuit simulation to compute the sound wave travel time and attenuation amplitude (equivalent depth) of different depths within the full range of the pulsed sound wave. Finally, the full-range equivalent measurement of the single-beam echo sounder is realized.

Considering the sound velocity distribution in the ocean approximates vertical stratification [8-9], horizontal distance measurement is used in this paper instead of vertical sounding for the measurement of the laboratory sink, and the value is transmitted. The horizontal sound velocity is relatively fixed, which solves the problems of uneven sound velocity and bending of the sound waves [10-11]. Based on the above principles, it is feasible to realize the full-range accuracy verification of the single-beam echo sounder in a laboratory sink of limited size.

3. Testing System Design

3.1. System Design

The schematic of the design of the detection device for the single-beam echo sounder is shown in figure 2. In the figure, 1 is the transducer of the single-beam echo sounder that is to be tested; 2 is the laser rangefinder (standard); 3 is the screw; 4 is the slider; 5 is the transducer; 6 is the sound-absorbing material; 7 is a laser reflection target; 8 is a standard hydrophone; and 9 is an underwater acoustic response device.
Specifically, in the five-sided anechoic water sink, the transducer of the laser rangefinder and the single-beam echo sounder are located on the same vertical plane. The two laser reflection targets are on the same vertical plane as the hydrophone and the transducer of the response device. The laser rangefinder is a standard device used for traceability and can accurately obtain the distance between the laser rangefinder and the two reflecting targets. The transducer of the single-beam echo sounder to be tested emits pulsed sound waves, which are received by the hydrophone, and are delayed and attenuated by the signal processing module (the response circuit) of the underwater acoustic response device; then the sound waves are processed by the transducer of the response device, after which the signal is sent back to the single-beam echo sounder to simulate the equivalent depth measurement. The equivalent distance can be expressed as the equation (4):

\[
D_t = \frac{R_1 + R_2 + c \cdot \Delta t}{2}
\]

where \( c \) is the average sound velocity in the water tank and \( \Delta t \) is the processing time in the water acoustic response device, which is a fixed value.

The transducer of the single-beam echo sounder to be tested receives the echo signal of the transducer of the answering device and displays the real-time water depth observation value \( d_t \), which is compared with the standard equivalent distance \( D_t \) to realize its accuracy verification.

4. Verification Test
The detection device is based on the construction of the velocity detection flume of the East China Sea standard Metrology Center of the State Oceanic Administration. Moreover, the testing method and the equivalent measurement function of the detection device are tested and verified using the single-beam echo sounder (model hd380) from Hi-Target, which also provides the data and technical basis for the optimal design of the detection device. The equipment installation layout is shown in figure 3 and figure 4.
The main purpose of this test is to verify the delay and attenuation performance of the underwater acoustic response equipment, and hence, we select “continuous” mode on the upper computer software interface, and configure the relevant parameters, as shown in figure 5.

In the test, the equivalent measurement depth is set as 12 m, 16 m, 20 m, 24 m, 28 m, 32 m and 36 m. The underwater acoustic response equipment realizes the equivalent measurement of the single-beam echo sounder using the corresponding delay time, transmission attenuation, receiving gain and other configuration parameters, and response processing. The measurement data interface of the single-beam echo sounder is shown in figure 6.
The test results show that through the parameter setting of the upper computer control software, the underwater acoustic response equipment can effectively and reliably carry out the corresponding and accurate signal processing.

5. Conclusion
In this study, we propose a detection method and a device design based on equivalent measurement which employs a circuit equivalent to simulate the long-distance propagation of the sound waves in an anechoic environment. The proposed device aids in achieving the full-range equivalent measurement of the single-beam echo sounder within the limited range of the laboratory sink. Verification tests show that the proposed method is feasible and provides a novel technical approach for the accuracy detection of marine acoustic instruments.

In the future, we plan to further explore the influence of sea-water sound velocity, sea-water propagation loss, seabed reflection loss, sea-surface reflection loss, and other factors on the measurement of the single-beam echo sounder using the detection device proposed in the present paper. The influence of various factors can be quantified through parameter setting, and the equivalent measurement of different sea areas (sea-water sound velocity distribution and sediment type) can be realized in a laboratory sink measurement environment. Moreover, it is an effective supplement for the performance test of single-beam echo sounders to obtain the adaptability and index of the instrument to be tested in various environments.

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