Echo signal simulation system

Feng Gao¹, Yang Zhang, Zhenshan Wang and Guijuan Li
Science and Technology on Underwater Test and Control Laboratory, Dalian, China

¹E-mail: gaofeng798113@sina.com

Abstract. In order to meet the demand of realistic simulation for complex target echo signal in water, the indirect method of frequency domain is employed to simulate the target echo signal in this paper. The plate element method is first used to forecast complex target echo characteristics in typical water. After generating frequency response function data, the data is imported into the echo signal simulation system. The system adopts FPGA real-time signal processing system based on PXIe bus. It receives hydrophone output signal by A/D sampling, extracts the incident acoustic signal and makes frequency domain transformation. After multiplying the transformed signal and frequency response function, scattering echo spectrum is obtained. And then the time domain transformation is made to get the time series of the echo signal. The series is loaded into the transmitting transducer by the power amplifier and the echo signal is simulated. The system has the high fidelity of the model, stable and reliable hardware system, and software system for easy operation.

1. Introduction
With the development of the intelligent water weapon and underwater acoustic countermeasures, the requirement of simulation fidelity for acoustic simulator enhances unceasingly [1]. In recent years, the working way of the acoustic simulator have been gradually developed for the forward based on the target echo response by a simple echo forward. This kind of simulation system based on the target echo response can make simulation for different objectives and different incident angles echo signal. Echo simulation system proposed in this paper makes target echo simulation by using frequency the indirect of method domain and adopts FPGA real-time signal processing system based on PXIe bus [2-4].

2. The system composition
The structure diagram of the proposed system is shown in Figure 1. It consists of four parts: the sound signal input module (including receiving sensor, signal conditioning and A/D acquisition), the real-time signal processing module (including time domain extraction of input acoustic signal, frequency domain transformation of signal, scattering echo spectrum calculation and scattering echo time domain signal generation), the acoustic signal output module (including D/A signal transformation, power amplifier and transmitting transducer) and the offline calculation module (including the high performance computer, the frequency response function at the time of the different incident angles, and a callable file stored).

3. The target echo simulation method based on the indirect method of frequency domain
The indirect method of frequency domain forecasts echoes from the perspective of information system. It makes the incident acoustic waveform transformation of the target as an information system. $s(t)$ is
the incoming signal of the system input, \( y(t) \) is target echo of the system output, system function \( h(t) \) is another kind of description form of target scattering sound field and \( y(t) = s(t) * h(t) \). The simulation flow chart is shown in Figure 2.

![Simulation Flow Chart](image)

**Figure 1.** The structure diagram of the proposed system.

**Figure 2.** The simulation flow chart of echo signal.

![Simulation Flow Chart](image)

**Figure 3.** The flow diagram of target echo simulation.

Acoustic scattering of the target can be regarded as a linear system response to the incident waves. The transfer function of the target \( H(f) \) is determined according to the mathematical model of the target, then according to the principle that the time domain response of linear system and frequency
Domain response corresponding to each other, transient echoes of the target \( y(t) \) can be obtained by Fourier inverse transformation to the steady state response of the frequency domain. The target echo time domain method obtained in the frequency domain is called an indirect method of frequency domain. The flow diagram of target echo simulation is expressed in Figure 3.

The frequency response functions in Figure 3 is calculated beforehand through high performance computer by using plate element method. This method is based on Cauchy Hoff approximate calculation target scattering sound field in water and uses a set of plane plate element approximate shape target complex curved surface. All the plates element scattering sound field is total scattering sound field approximation, thus the target echo characteristics is obtained. In the method of physical acoustics, Cauchy Hoff Formula for scattering problems is shown as

\[
\Phi_s = \frac{1}{4\pi} \int \left( \phi_s \frac{\partial}{\partial n} \left( e^{ikr} \right) - \frac{\partial \phi_s}{\partial n} \frac{e^{ikr}}{r} \right) dS
\]

(1)

Using the plate element method, the Cauchy Hoff Formula (1) is solved numerically and the scattering transfer function \( H_f \) of the target is obtained [5].

![Figure 4](image_url)

**Figure 4.** The simulation of target echo signal: (a) the incident signal, (b) the echo signal with incident signal 0°, (c) the echo signal with incident signal 90°.
The echo the international general Benchmark model is simulated by using this method. Simulation conditions: free sound field, 2000 meters from the sound source to the target, high Angle 0 °, incident signal form LFM, incidence Angle 0 ° and 90 ° and pulse width 0.02 s. The simulation results are shown in Figure 4.

4. The software development
The system is developed by using the Labview software [6-9], and the software interface is shown in Figure 5. In Figure 5, the upper part is the display area for receiving signals, lower left part is the display area of the intercept signal and the emission signal, measuring signal frequency band selection is on the right, including the selection of the signal length, angle and strength, and the system control settings including magnification and the frequency band.

![Figure 5. The system software interface.](image)

The flow diagram of system software is shown in Figure 6.

![Figure 6. The flow diagram of system software.](image)
Figure 7. The simulation map of the sea test.

Figure 8. The measured signal on the sea: (a) the signal received by simulation system, (b) the echo simulation signal of incident Angle 0°, (c) the echo simulation signal of the incident Angle 90°.
5. The sea test validation

The system is verified by sea test in Dalian. The simulation map of the sea test is shown in Figure 7. Test signal launch ship is 1000 meters from echo simulation ship, and signal launch ship launches 20 meters pulse width linear frequency modulation signal. Figure 8(a) is the signal received by hydrophone on the echo simulation ship. By using the echo simulation system, the emission signal under different incident angles can be simulated, and the hydrophone on its launch sound source 1 meter can monitor the emission signal. Figure 8(b) is the echo simulation signal of incident Angle 0°. Figure 8(c) is the echo simulation signal of the incident Angle 90°.

Test results show that when the incident Angle is 0°, the echo is composed of two child echoes, however, when the incident Angle is 90°, the echo is from a child echo. The test results are similar with the simulation results, but slightly waveform difference is caused by channel bandwidth.

6. Conclusions

This paper proposes a kind of target echo signal simulation system based on a frequency domain indirect method. The system can simulate the echo of underwater complex target under different incident angle. Test results show that the system is stable and reliable.

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