Design of marine environmental noise signal generation system based on MATLAB, LabVIEW and FPGA

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Abstract. Marine environmental noise is a background interference field produced by various underwater sound sources. The characteristics of marine environment vary with time, place and frequency. In order to simulate the marine environmental noise signals with different time-frequency characteristics, a real-time generating system of marine environmental noise signals is designed based on MATLAB, LabVIEW and FPGA. According to the probability distribution of the measured frequency characteristics of marine environmental noise, the random signals with specific frequency response are calculated and generated in real time and continuously. The pool test results show that the signal generation system has the characteristics of stable real-time calculation and signal generation. Based on the marine environmental noise signal generation system designed in this paper, time-domain waveforms with specific spectrum characteristics are generated, which will provide technical support for the research of random signal processing algorithm under laboratory conditions and the performance analysis of underwater acoustic equipment under different marine background conditions.

1. Introduction

Marine environmental noise is a background interference field produced by a variety of underwater sound sources. The characteristics of marine environment vary with time, place and frequency. In order to simulate the marine environmental noise signals with different time-frequency characteristics, the random signals with specific frequency response should be generated in real time and continuously, according to the probability distribution of the measured frequency characteristics of marine environmental noise [1]. Existing methods [2-6] were designed calling marine environmental noise data generated by the model in advance. The length of the data generated by using these methods was limited. Moreover, these methods can only send the segment data repeatedly and do not have real time. However, the proposed method in this paper can calculate and generate data according to the model in real time, which is not limited by the length of the data, so as to not generate the same data repeatedly.

In this paper, the continuous spectrum model of Marine environmental noise is first analyzed and established, and then the hardware platform of the system is designed and built. Several key technologies used during developing signal generation module by using the LabVIEW software are introduced. Finally, the test system is constructed. The test results verify the effectiveness of the proposed system.
2. Continuous Spectrum Model of Marine Environmental Noise

The simulation of continuous spectrum is actually how to produce random signal having a set of power spectral shape and amplitude distribution [7]. In this section, a model of continuous spectrum of marine environmental noise is proposed. A linear system is first constructed, which is the same as frequency response of the marine environment noise spectrum shape; When the Gaussian white noise is inputted, and making it through the system whose frequency response is $H(\omega)$, the Gaussian noise is produced, whose power spectrum is $|H(\omega)|^2$. According to the theory of linear system, if the input sequence $x(n)$ is a stationary random signal sampling sequence, after passing through a linear system of a unit impulse response, it is still a stationary random signal. On the basis of the above discussion, we design the FIR filter satisfying the requirement of marine environmental noise spectrum to filter Gaussian white noise, thus, the simulation of the continuous spectrum component can be realized [8]. Marine environmental noise simulation block diagram is shown in Figure 1.

![Figure 1. Marine environmental noise simulation block diagram.](image)

2.1. The generation of Gaussian white noise

Generally, the subject of the marine environmental noise is assumed to be a stationary ergodic random process. First, a long period of Gaussian white noise random sequence is obtained by using the Box-Muller method. The sequence obeys Gaussian distribution and owns a pure white of power spectrum. Let $\beta_1$ and $\beta_2$ denote two independent random numbers obeying $N(0,1)$ distribution,

$$n = (-2\ln \beta_1)^{1/2} \cos 2\pi \beta_2.$$  \hspace{1cm} (1)

2.2. Filter design

First, a $n$-order low pass filter is designed, whose cut-off frequency is $f_L$, sampling frequency is $f_s$, and pulse function is $H(n)$. $f_L$ is appropriately selected according to the scope of the marine environmental noise bandwidth. The feature of the filter is that the amplitude of each frequency point is random number meeting a certain probability distribution after statistical analysis of the marine environmental noise data, so it can effectively describe the statistical features of environmental noise of each frequency point [9].

And then, after Fourier transform is carried out on the designed filter, the amplitude frequency function of the filter $H(f)$ is presented as

$$H(f) = F[H(n)].$$  \hspace{1cm} (2)

After the function $H(f)$ is remoulded, a new function $H_{zc}(f)$ is obtained. After multiplying $H_{zc}(f)$ and $H(f)$, we get a new amplitude frequency function of the filter meeting the noise spectrum characteristics

$$H_{zc}(f) = H_{zc}(f) \times H(f).$$  \hspace{1cm} (3)

Finally, after carrying out the inverse Fourier transform for the function, we obtain
\[ H'(n) = F^{-1}[H_x(f)] . \]  

FIR low-pass filter is obtained meeting the spectrum characteristics of the marine environmental noise.

3. Design of the marine environmental noise signal launch system

Signal generated by the signal source, after balancing adjustment, shall be launched and loaded to the transmitting transducer by the power amplifier, and then carry out acoustic radiation in the water [5]. System principle block diagram is shown in Figure 2.

![System principle block diagram](image)

**Figure 2.** System principle block diagram.

The design of the signal source is the key to implementing the marine environmental noise signal launch. The signal source is developed by using NI PXIE platform, which includes a PXIE Bus Case (PXIE1071 Model, 4 slot Case, 3 GB/S Bus Bandwidth), a FPGA processing board based on PXIE Bus (PXIE7857R Model, Kintex-7 FPGA Chip, 8 channel A/D, 8 channel D/A, 1 ms/s Sampling Rate), a piece of PXIE bus data transmission card (PXIE8301 Model, USB Type-C Interface, 2.3 GB/s Transmission Rate), and a host control machine.

4. Design and implementation of the signal launch software

The signal launch software is developed by LabVIEW software. First, a human-computer interaction interface is developed on the LabVIEW development platform. Then, two threads are established. One thread uses LabVIEW Script node calling MATLABE program to calculate the real-time marine environmental noise data, the other calls D/A module of FPGA to send data in real time. Data transmission between two threads is controlled by using FIFO technique. Software interface is shown in Figure 3.

![Software interface](image)

**Figure 3.** Software interface.
4.1. MATLABe node call

The use of MATLAB script node is a key technology in software development. It is the bridge to realize communication between the LabVIEW and MATLAB. The connection between built-in ActiveX control of LabVIEW and MATLAB Server is established to carry out data interaction, and MATLAB command and functions are called to realize the complex numerical calculation and analysis [10, 11]. Here, MATLAB script node call is real-time calculation of marine environmental noise continuous spectrum. Calculation process of marine environmental noise by using the MATLAB script node is shown in Figure 4.

![MATLABe node call](image)

**Figure 4.** Calculation process of marine environmental noise by using the MATLAB script node.

4.2. Data transmission

How data generated by MATLAB stably transmit to D/A module of FPGA and send is another key technology in the process of software development. Here, we use the double thread queue technology.
The data generation and data transmission are established in two different threads respectively. Data transmission is carried out through the DMA FIFO. FIFO depth is set through calculation. Data from the host is sent to the FPGA module. FPGA can send the data. When the data in the FIFO is reduced to a set value, the host sends the next batch of data generated by MATLAB in real time into the FIFO [12]. The program of data transmission is shown in Figure 5.

4.3. FPGA signal generation in real time
The FPGA signal generation program in real time is responsible for point by point sending the data transmitted by the DMA through D/A module [6]. The FPGA signal transmission program is shown in Figure 6.

5. Experiment test
Experiment test was carried out in the water tank. The marine environmental noise signal launch system sends noise signals (Frequency is 10 KHZ - 38 KHZ, amplitude is normalized, and phase is randomly generated, which conforms to the feature of the noisy signal), and receiving hydrophone receives the signals sent. Then, we collect and analyze the signals received with the collector. Experimental test of signal generation and collection and analysis results are shown in Figure 7. In the experiment, the signal sampling rate is 200 KS/s, FIFO depth is 10s and the initial length of the signal data in FIFO is 10s. When the length of the remainder signal data in FIFO is 5s, the signal data is
computed by calling MATLAB model and the computation time is not greater than 3s, which ensures that the real-time performance of the proposed system. When the length of the signal data in FIFO is less than 5s, the signal data generated by calling MATLAB model is saved in the FIFO. Therefore, the operation of the system is stable in this mode. Analysis results show that signal spectrum complies with the design requirements and meets the design purpose.

![Arbitrary Signal Generation Software](image)

**Figure 7.** a) The test result of the marine environmental noise signal generation, b) Collection and analysis results of the marine environmental noise.

6. Conclusions
In this paper, the marine environmental noise continuous spectrum model is first established, then the hardware system platform is designed. Moreover, we introduce a few key development technology used by the signal generation module. Finally, the test results verify that the proposed system is stable and reliable when the sampling rate is not more than 200 KS/s. The established marine environmental noise emission system can send environmental noise data calculated in real time.
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