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A new data acquisition and processing system for profiling sonar

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Abstract: A multi-beam chirp sonar based on IP connections and DSP processing nodes was proposed and designed to provide an expandable system with high-speed processing and mass-storage of real-time signals for multi-beam profiling sonar. The system was designed for seabed petroleum pipeline detection and orientation, and can receive echo signals and process the data in real time, refreshing the display 10 times per second. Every node of the chirp sonar connects with data processing nodes through TCP/IP. Merely by adding nodes, the system's processing ability can be increased proportionately without changing the software. System debugging and experimental testing proved the system to be practical and stable. This design provides a new method for high speed active sonar.

Keywords: profiling sonar; IP network; data acquisition; parallel processing; DSP

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1 Introduction

In recent years, with the development of sonar technology, there are higher demands for sonar signal processing system about large capacity and real-time signal processing capabilities. Most of traditional sonar's signal processing systems use dedicated hardware to complete specific data-processing tasks. That is, data conversion acquisition directly accesses transducer, and after the ADC (analogue digital converter), the data will enter into the digital signal processor (DSP)[1] for processing. Though such systems can work steadily for fixed transducer array and processing speed, once the transducer array changes or processing speed increases, they cannot work. Against the above limitations, based on actual project ("External detection of seabed oil pipeline"), an expandable multi-beam profiling sonar data parallel processing system based on IP interconnection is designed. Two TI's multimedia DSP (TMS320DM642) processors are used as a processing node in this new system, working in parallel, inter-board pipeline mode, and different nodes rely on IP network to realize interconnected parallel process. Some nodes could be increased or deleted to satisfy actual demand, for example, transducer array change, processing speed change and so on. At the same time, because data storage is an independent process, all processing nodes and data fusion upload could be easily realized, and this system is very suitably carried by small platform sonar for signal processing.

2 Structure and principle of profiling sonar system

2.1 Principle of profiling sonar system

The profiling sonar works in an active way, and the transmitting transducer is vertical to the seabed when launching bunch of wave beams. When the sound wave arrives at the seabed surface, it obtains a very strong echo because some energies are reflected. The other energies are transmitted into the seabed, continues transmitting to the deep inside the seabed. But due to continuous media inside the seabed (such as seabed rock, petroleum pipe line and so on), it can produce echoes[2,3]. Though some energies in this echo are lost due to scattering of the solid matter, some others are scattered back to the transducer. These echoes contain non-continual information about the media inside the seabed[4]. Therefore, distributed situation of buried objects may be fed back according to the seabed media's internal echoes. Relaying on the robot's movement paralleling to the seabed, the

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received signal of transducer is processed, then uploaded to the surface host to reconstruct the two-dimensional structure frame of the seabed profiling, and the three-dimensional section drawing can be obtained according to the height, range and localization of sonar in robot in successive processing.

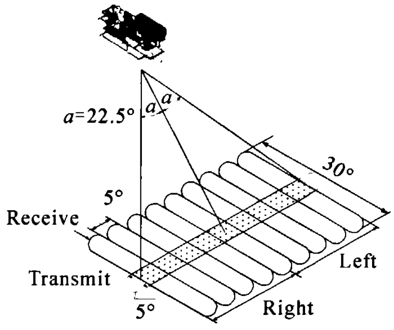


Fig.1 Diagram of the multi-beam profiling sonar's working principle

2.2 Structure of the profiling sonar system

The profiling sonar system used for external detection of seabed oil pipeline could be flexibly installed in the bottom or be hoisted in front of the robot. Considering the real-time and accuracy, the system is divided into underwater unit and the surface host, which are connected by optic fiber cable. The underwater unit is carried by ROV and consists of transducer array and underwater control processing module, which is made up of DSP control unit, transmitters and DSP parallel processing unit. The transducer array is mainly composed of the launch transducer, which has a direction of 45°×5°, and a receiving transducer consisting of nine 5° sensor elements. The part of receiver transducer containing some analog signal conditioning circuit can convert analog signal into digital signal in real time, and transfer it to underwater control processing module by IP network. The surface unit is composed of surface host, which transmits control signal by serial port and shows the detection results through screen. Fig.2 is the structure of profiling sonar.

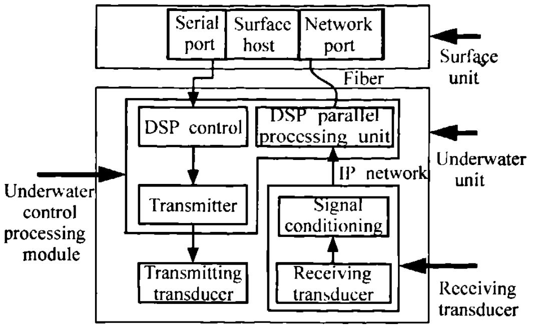


Fig.2 Structure of profiling sonar

3 Structure of parallel data acquisition and processing

3.1 Data acquisition and network transmission

The receiving transducer part is responsible for conditioning the received analog signals (e.g. amplifying, filtering and automatic gain control), and converting analog signal into digital signal with a 500 kHz sampling rate. Then digital signal is transferred to the underwater DSP parallel processing unit through network. The reasons for choosing network transmission are that firstly, the physical layer network's data transmission speed could meet the requirements of 500 kHz sampling rate and 16-bit data output of 9-channel A/D conversion. This ensures synchronized data transmission and A/D conversion. Secondly, the network transmission can realize one-point sending and multi-point receiving, namely, both point-to-point and broadcast transmission could be achieved. Thus different frames are processed by different nodes, and multiple receiving points could deal with a group of frames, thereby the system's processing speed could be improved. So the profiling structure could have a higher refresh rate of frames. Fig.3 shows the circuit diagram of data acquisition and network transmission.

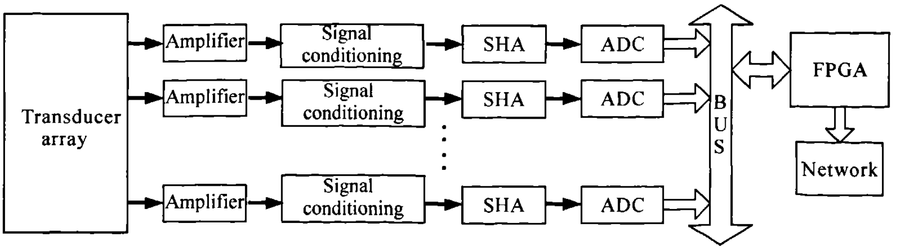


Fig.3 Data acquisition and network transmission

In order to inhibit the strong impulse reverberation after the launch and compensate transmission loss, the automatic gain control (AGC) circuit whose effective gain range could reach 40 dB is used. In order to effectively remove all kinds of disturbances (such as environmental noise, low-frequency electrical noise, etc.), a group of band-pass filters which has the center frequency of 50 kHz and anti-aliasing function are inserted after the amplifier. As ADC's input range and the filter output signal do not match, a buffer amplifier is adopted to generate necessary gain. Then the fully differential operation amplifier will adjust single-ended signals into differential form. On the one hand, the circuit can eliminate common mode interference, and on the other hand, A/D requirements are met. Fig.4 shows the diagram of signal conditioning.

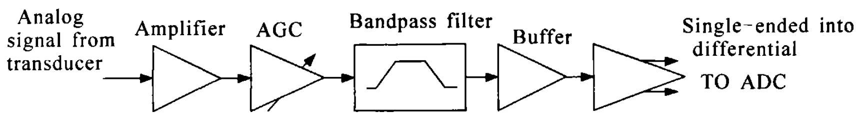


Fig.4 Signal conditioning

ADC of the data acquisition system uses TI's ADS8323, which is capable of 16-bit A/D conversion and whose maximum sampling frequency could speed up to 500 kHz. After the power supply isolation filtering, analog conditioning, differential input, and other treatment, ADC can reach effective 13-bit and the board noise of system is only about 0.6 mV through sophisticated PCB wiring. Fig.5 shows the board noise of this data acquisition system.

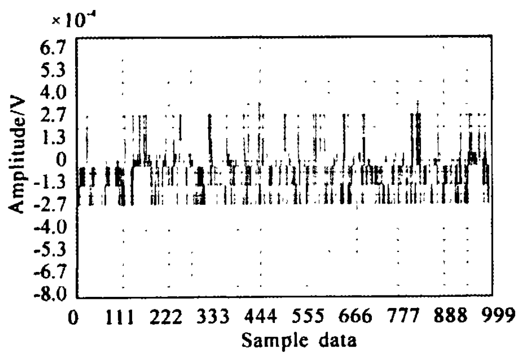


Fig.5 The result of A/D

After 9-channel A/D converting, data are cached, packed to frame, and added with header by the FPGA, then every frame data is transferred to the underwater control processing module at a speed of 500 kilo frames per second by network. Fig.6 shows the structure of data frame. After processing, receiver can recognize the data from different channels.

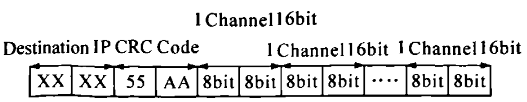


Fig.6 Structure of the network transmitted data frame

3.2 Parallel pipeline structure of DSP processing node

To obtain higher detection capability, the multi-beam profiling sonar system uses linear frequency modulation (LFM) with 35~65 kHz bandwidth to transmit signal, and the system's sampling rate is 500 kHz. When the acquisition time is 15 ms, the effective detection distance can reach 11 m. To profile seabed, the 9-channel received signals need to be further processed, e.g. band compensation, beam-forming, correlation, side-lobe suppression, and FIR filtering[5]. At the same time, the systems should be able to show real-time result at a speed of 10 frames per second (fps) or above and save it to disk.

To meet the multi-beam profiling sonar's demand for real-time signal processing of large-capacity data at a high speed, the structure of parallel pipeline of two DSP processors is adopted in the signal processing system. Fig.7 shows the structure of parallel processing board.

This board is made up of two TMS320DM642-600 processors, which are of the highest-performance, fixed-point DSP generation in the TMS320C6000™ DSP platform, and based on the second-generation of advanced very-long-instruction-word architecture (VelociTI.2™). With the performance of up to 5 760 million instructions per second (MIPS) at a clock rate of 720 MHz, the DM642 device offers cost-effective solutions to high-performance DSP programming challenges. Meanwhile, the Ethernet media access controller (EMAC) provides an efficient interface between the DM642 DSP core processor and the network.

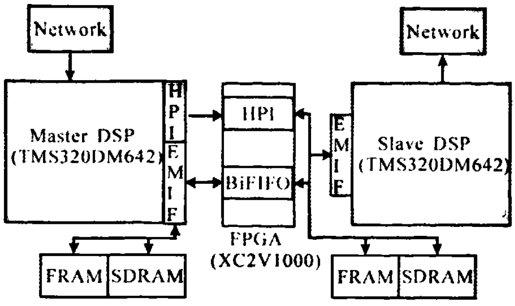


Fig.7 Structure of parallel process

In the board, the left DSP is slave-DSP responsible for receiving data from transducer through network according to the refresh rate and speed requirements, storing the received, converted signal data on its external SDRAM. When a whole frame data transmission is finished, two DSPs enter into the parallel processing procedures. Left DSP is responsible for receiving, and right DSP is responsible for reading the internal and external SDRAM data of the left DSP through HPI interface. These two DSPs exchange data, and transmit mail information through a dual-port FIFO. To ensure load balance of the two DSPs in the signal procession, the tasks that will be processed by profile sonar need to be divided. The multi-beam sonar's signal processing needs to realize some algorithms such as 16-bit data FFT, frequency-domain beam-forming, frequency-domain correlation algorithm, IFFT, time-domain FIR filtering, and time-domain weighted sidelobe suppression for 9-channel data, and each channel has 7 500-point, 16-bit data.

Compared with the past sequence execution for single system, the parallel pipelined implementation of the whole system could greatly reduce the execution time of the whole tasks. To ensure DSP load balancing of the two tasks and that the pipeline parallel processing boards can process data really in parallel in a pipeline form, the tasks are divided in each DSP. Taking two DSP processors for example, in order to keep load balance of each, the division result is shown in Fig.8.

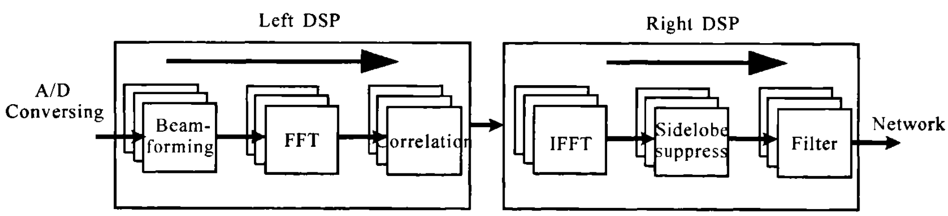


Fig.8 Parallel task division

For example, to process 5 frames in one node in one second, the system tasks are subdivided into several parts, each has the same processing time[6]. The pipeline's execution time depends on sub-process. Fig.9 shows the system's pipeline processing time-space chart.

Table 1 shows the time consumption under different distribution programs in the program debugging. As shown in Table 1, data processing is more balanced when the left DSP processes 5 channels' data and the right DSP processes the other 4 channels' data.

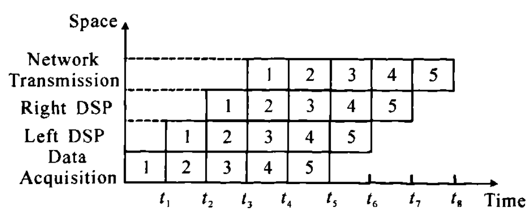


Fig.9 Pipeline processing time-space in the parallel processing board

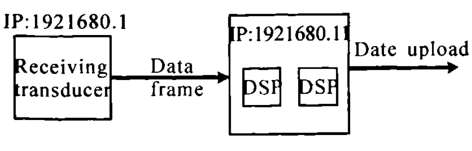
Table 1 Task division

Plan of task division	Left 5 Right 4	Left 6 Right 3	Left 7 Right 2	Left beam-forming, Right else	Left process, right transmission
Time consumption/ms	83.667	87.560	90.425	122.05	130.99

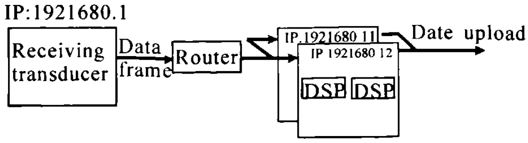
3.3 Inter-board parallel processing based on IP network

Every processing node of multi-beam profiling sonar system can process 10 frames' data corresponding to 15 ms of the acquisition time, which can basically meet the need of display. But if the system demands longer detection distance, more data capacity and higher display rate, the parallel processing board should have higher data processing rate. Therefore, several processing nodes are connected each other by IP network. This is the basic structure in our processing system.

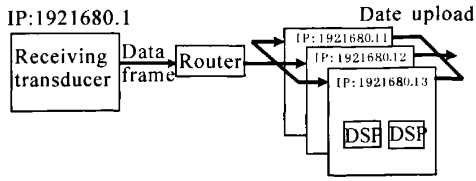
The single processing board of the system has the processing ability of 10 fps. If the refresh speed of 20 fps is demanded, the processing speed of system should be accelerated with the same speed. Ordinary parallel processing structure needs much auxiliary work when increasing the system processing units. For example, the procedure and logic of the electronic system as well as the electric circuit board need to be greatly improved. While the multi-beam section sonar system based on IP network architecture only needs to increase the same processing board in physical structure when increasing the system's processing speed. The procedure and logic of this system don't need to be modified too much. It only needs to modify corresponding IP address of the board to enable the transmitting network port and the receiving transducer transmit separately from one node to another node. The starting of data packet of each frame should be marked to designate IP address. After switching on, the system will examine the numbers of IP in local area network, then obtain the IP address of each board in the system by means of sending and receiving packets. The system's IP addresses can also be fixed; then the transmitting port of network device will transmit each frame to different processing boards circularly. And then each processed frame data will be uploaded to the surface host for display by network, so the processing speed of the system can be enhanced linearly. Fig.10 details 1-3 processing boards based on the IP network transmission.



(a) Processing chart of the first processing node



(b) Processing chart of the second processing node



(c) Processing chart of the third processing node

Fig.10 Flow of parallel processing based on IP network

High-speed DSP can easily achieve parallel process based on IP network with the help of network interfaces of two DM642 processors. The receiving transducer working as server transmits different data frames to different processing nodes. After being processed, the data frames received by the processing nodes are transmitted from the other network port to the surface host by IP network. In order to avoid confusion, different IP addresses are assigned to each DSP[7]. When uploading data, the surface host will receive different processing results from different processing nodes by router, and show the result on the screen by the format of data frame. As a result, the processing ability of system can be improved by increasing the amount of processing nodes.

4 Experiment

In order to verify this new data acquisition system of sonar, the experiments were done respectively in the pool at the College of Underwater Acoustic Engineering, Harbin Engineering University, in the tank in the suburb of Harbin and in the oil field of Bohai Sea. In all trials, the system was stable and reliable, and had achieved the processing speed of 10 frames per second. Fig.11 shows the test result obtained in the tank.

An aluminum tube of 3 cm in diameter was hoisted in front of the transducer, and a petroleum pipeline of 30 cm in diameter was placed behind. The figure has clearly shown the aluminum tube and the front and back walls of the petroleum pipeline. It was detected successfully.

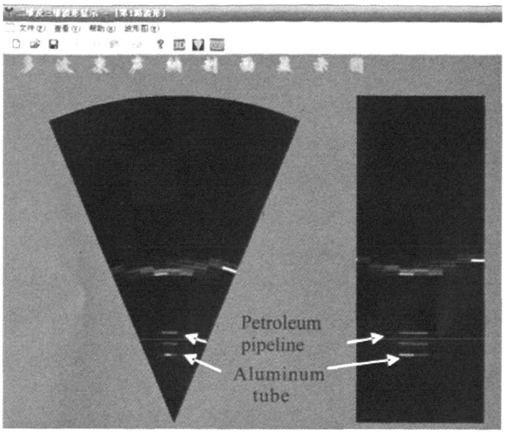


Fig.11 Experiment result

5 Conclusions

This paper has introduced the DSP parallel processing system, which has high-accuracy data acquisition structure based on the IP network. This kind of new data acquisition and processing structure has broken the fixed data acquisition structure of conventional active sonar (e.g. imaging sonar, side-scan sonar), and provided a new data acquisition and processing platform for the high-speed multi-beam array signal processing sonar. The debugging and experimental results indicate that the design of software and hardware structure in this system is feasible; and the system can work stably and effectively in the pool and lake trials.

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