Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Design of Distributed Monitoring System Based on Vibration and Acoustic Signals

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PACS: 43.58.-e

ABSTRACT

The rotating and reciprocating machines, like engines, electromotors, pumps, have a broad-spectrum application in modern ship design and manufacture. As a complex system, it is well known that some incidental malfunction of those equipments may give cause for critical accident during navigating. In order to improve the safety and reliability of the ship, a distributed system based on network is proposed and developed to monitor the important equipments. The monitoring system, consisting of a console, several sampling devices and hundreds of sensors, is designed for permanent installation in ships under realistic working conditions. The vibration signals are filtered and converted by the sampling devices and sent to console via the LAN(Local Area Network). The information is analyzed and stored by the computer assembled into the console, to realize the ship state monitoring and faulty detection. Considering the convenience of the setting sample rate for each channel respectively, all signals are sampled by the highest sample rate to satisfy the Nyquist Theorem, then filtered and downsampled in FPGA(Field Programable Gate Array). Up to now, the hardware, embedded software and information manage software are achieved.

1. INTRODUCTION

With the development of shipbuilding and electronic technology, the ships are becoming more complex and intelligentized. The faulty detection and condition monitoring system of marine devices is indispensable for modern ships' safety, reliability, transportation efficiency and economy. On-line condition monitorring of the marine devices, e.g. diesel engine, pumps, compressor and screw propeller, detects and localizes the faults through malfunction analysis, and give alarm information at the first time. The vibration and acoustic signals include important information of the devices' running condition. The monitoring system can also be used to measure and analyze the vibration state of newly assembled marine device, to evaluate whether its mechanical operation stability measures up the design criterion, and similarly, this is applicable to the devices after maintained. The condition monitoring is one of the important measures for preventive maintenance. The deteriorative degree of machine is achieved based on vibration and acoustic analysis, and the faulty component will be replaced before it is disabled completely. The maintenance based on condition monitoring, rather than periodic maintenance and breakdown maintenance, avoids the overdone maintenance and shortage of maintenance, which will bring the saving of resource and time, and improve the safety of navigation.

Various mechanical condition monitoring research are promoted. Chetwani et al. researched the motors online condition monitoring system based on current information processing [1]. Charles et al. researched the diesel engine combustion related fault detection based on vibration signal [2]. Johnson et al. developed a smart sensor array black box for distributed structural health monitoring based on vibration [3]. Giron-Sierra designed and implemented a monitoring and control on-board system for ship model experiment, and it is linked to the off-shore system by the wireless mode. It's a DSP system for data sampling, analysis and communication [4]. Jie Yang and Ting Xue et al. designed a distributed on-line vibration monitoring system, to provide real-time detection to the rotating mechanism of vessels, of which, the network is organized by the CAN bus [5-6]. Wangqiang Niu described the detailed characteristics of the integrated monitoring systems of four ships in different sizes and types. All of the monitoring systems have a double layer network topology, of which the bottom layer is a field bus [7]. Yang Wang et al. developed an on-line vibration condition monitoring system of hydro generator. All signals are acquired by the fieldnodes, and transferred to PC by the LonWorks bus [8]. However, all field buses above are inefficient for large numbers of monitoring data communication.

Considering the limitation of field bus, Ethernet is considered because of its ease of system extension, good communication performance, higher availability, and so on. Thompson presented the networked aircraft, the application of Ethernet and wireless technologies for on-board systems remote monitoring, testing and control [9]. In this paper, we designed and implemented a distributed monitoring system based on Ethernet communication. It consists of a server assembled in the console, and several sampling nodes. The sampling nodes are distributed for scattered monitoring area, so as to connect the transducers to the sampling node nearby to confirm the data validity and reduce the cable costs and weight. The signals are converted and acquired by the sampling nodes, and sent to server via the LAN. Then the data are stored and analyzed in the console server, to realize the device vibration measurement and condition monitoring.

The remaining part of this paper is organized as follows. Section 2 presents the structure and overview of the distributed on-line monitoring system. Section 3 describes the system design. Section 4 gives the details of data communication technologies based on VxWorks. Section 5 discusses the system reliability design. Section 6 gives the conclusion.

2. STRUCTTURE OF THE MONITORING SYSTEM

The hierarchy of the distributed monitoring system consists of three parts: Server, Sampling Node, and Sensor.

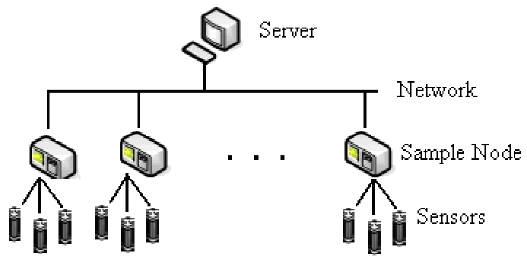

Figure 1. The hierarchy of the distributed monitoring system

The great mass of sensors are accelerometers, which are employed to sense the vibration of various marine mechines. At the same time, a small amount of microphones are included to monitor the airborne sound. The sensor analog signal, preprocessed by the preamplifier embeded in the sensor, is the input of sampling node. It passes through the post amplifier, low-pass filter, and then is translated into digital signal by the A/D converter. The data are acquired by the sampling node controller, and sent to network after packed. Finally, the sensor signal data are downloaded by the server, which executes the function of signal processing, data analysis and storage management. The server also has a human-machine interaction interface, being able to input the operator instruction to control the sampling node, and display the real-time data analysis results.

3. DESIGN OF THE SYSTEM

Sampling Node

The sampling node consists of node controller, signal conditioning module, signal acquisition module, and power supply. The signal conditioning and acquisition module function block is shown as Figure 2.

The signal conditioning module integrates 32 signal channels circuits, each of which includes one post amplifier, one anti-overlap filter circuit, and can also offer Constant Current Line Driving (CCLD) or Constant Voltage Line Driving (CVLD) supply for the sensor preamplifier. The maximu cut-off frequency is 20 kHz. The signal acquisition module, being provided with 32 channles A/D converter, converts the analog signal into digital signal. FPGA (Field Programmed Gate Array), being the controller of acquisition module, implements the A/D converter control and reads data from it. The acquisition precision is 24 bits, and maximum sample rate is 50 kHz. A cut-off frequency configurable Low-Pass filter is structured in FPGA. For the channels that working at lower sample rate (fs/2, fs/4, ect.), the data are filtered by the corresponding Low-Pass filter, and down sampled to reduce the sample rate. In fact, each channel sample rate can be set individually. The flexibility of sample rate setting reduces the data stream. FPGA communicates with the node controller by the PCI Bridge synchronously.

A PC104plus module running at 400MHz is used for node controller which requires +5 V and +12 V power supply. It has one 10/100Mbps Ethernet interface supporting wake-on-LAN, 1.6 seconds interval Watchdog timer, and 64MByte SDRAM.

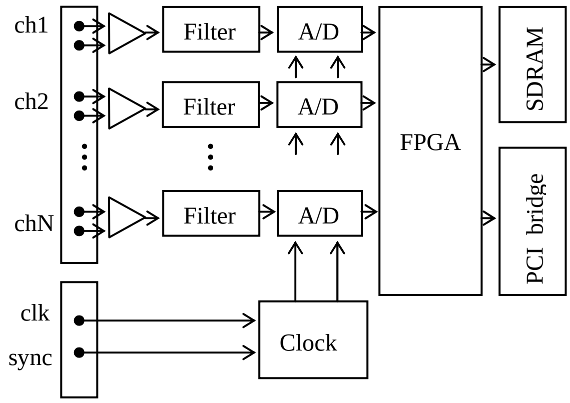

Figure 2. The signal conditioning and acquisition module function block

Console

A server with Intel Dual-Core Xecon CPU, 2 GBytes memory, and Compact PCI (CPCI) bus is assembled in the console. Two disks are employed in the computer system, one of which being solid state disk (256GB) is used for operating system storage, and another being hard disk (1TB) is used for data storage. The software interface is provided to the operator for sampling nodes and data management, and data analysis results display.

Software

The software designed is shown as Figure 3. Windows OS is adopted in the server, and for the purpose of embedded software running stability and real-time capability, VxWorks OS is employed in the sampling node.

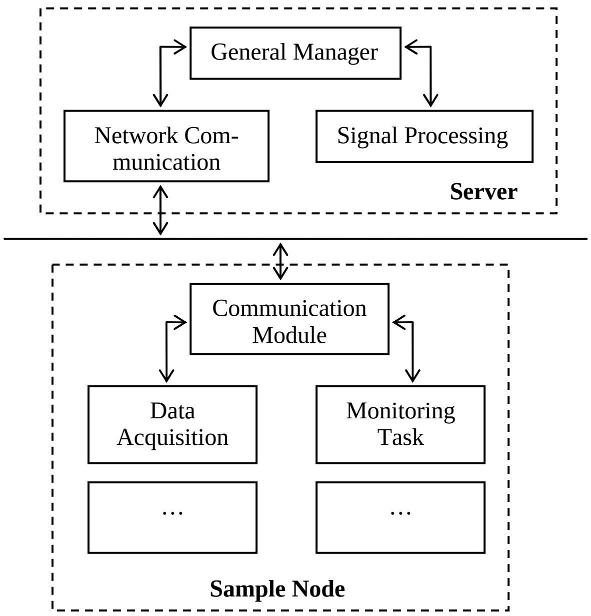

Figure 3. The system software design

The general management inlcuds input/display interface, data storage and task scheduling. The server network communication module implements the communication between the server and sampling nodes. The data is read from the sampling node to server by the ethernet network. Part of the signal processing algorithms has been implemented to execute the information analysis.

As a data exchange hinge, the network communication module is the core of the sampling node embeded software design. Most of the tasks either belong to the communication module, or have the data exchange with it, the data acquisition and monitoring modules, for example. The details will be discussed in the next section.

4. DATA COMMUNICATION TECHNOLOGIES BASED ON VXWORKS

TCP/IP protocol is employed for network communication between the server and sampling nodes. Based on which, two logical connections, data connection and monitoring connection, are established between the client and server. The data connection transfers the operation command from server to sampling node, and returns the sampled sensor data, node setting and other information to the server. Monitoring connection takes charge of the network connection monitoring. The detection is repeated every dozens of seconds, and reconnection will be active as soon as the network is unblocked, if the disconnection has ever been detected.

The software is designed in the form of modularization and multi-task. The semaphores and message queues are used to synchronize and schedule the task activity. As the message buffer and being accessible to multi tasks, the message queue is competent not only for the task synchronization, but also for the data exchange among various tasks.

Firstly, a large scale data buffer is devided into some segments with adjacent address, which is allocated permanently during the software initialization (see Figure 4). The data sampling task puts the A/D conversion results into the buffer segment one by one, at the same time, the start address and length of corresponding segment are pushed into the message queue. This event will be detected by the data sending task and the information will be read from the message queue, according to which the sample data is sent to network. The message queue takes the role of buffering and transferring the sample data buffer information. Once the data sending stops temporarily because of network being blocked, the sample data will still be stored into the data buffer, until the buffer is full, or the network communication is resumed.

Besides the sample data, the sampling node running state and sample setting etc. can be uploaded to the server through the message queue. According to the urgency degree of message, the priority is determined in the message queue. The node state monitoring task has the top priority of sending the running state information.

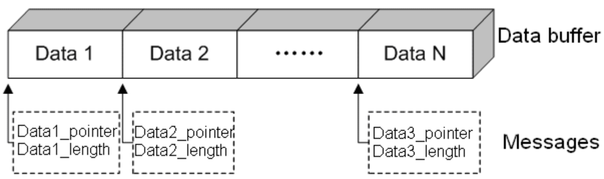

Figure 4. The data buffer structure

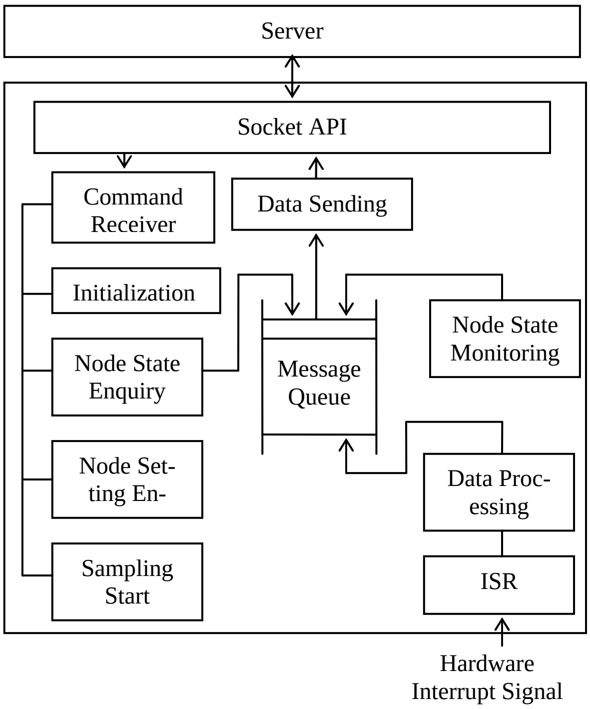

Figure 5. The communication based on message queue

5. SYSTEM STABILITY DESIGN

As a shipborne automatic condition monitoring system, the running stability of the system itself is very important. Especially, the stability design of the sampling node, being usually assembled in unmanned environments, is necessary.

Network Connection Monitoring – As mentioned above, a special network connection is established to monitor the network condition.

Device Operation Temperature Monitoring – Two temperature sensors are planted in the signal acquisition module to monitor the sampling node operation temperature. It is sampled by the embedded software periodically, and will be sent to the server if its value is beyond the dangerous threshold. Of cause, it can be enquired by the operator at any moment. If the sampling node runs at higher temperature continuously, it may be turned off automatically.

Memory Management – The memory management is the key aspect for the software long-time running. The memory leaks and memory fragments must be avoided. The effective and simple method is to avoid the continual memory allocation and release. In the sampling node embedded software system, the memory allocation is completed during the software initialization, and the allocated memory is never released except only two tasks, which may be released and recreated in the operating process. While, the tasks should be assigned to their original memory addresses according to the First-Fit memory allocation algorithm when they are recreated.

Watch Dog – The watch dog can be active to resume the embedded software after breakdown, which may be caused by the background disturbance, power fluctuation, or logical error, and so on. A task is created to reset the clock periodically.

6. CONCLUSION

This paper presented a distributed monitoring system. The sampling node, consisting of node controller, signal conditioning module, signal acquisition module, acquires and transfers the sensor data to the server in real time. The monitoring data acquisition platform has been established. More research will be carried out at the following steps. Besides the shipborne machine monitoring, in fact, the designed distributed monitoring system can also be applied to other vehicle monitoring, industrialized production monitoring, etc.

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