Dongmei DU[1], Qing HE[1], Zirui HE[2]

Key Laboratory of Condition Monitoring and Control for Power Plant Equipment, Ministry of Education, School of Energy Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, China (1)
Department of Electrical and Electronic Engineering, the University of Bristol, Bristol BS81UB, UK (2)

A Novel Vibration Monitoring System Based on Wireless Sensor Networks

***Abstract**. Considering the application limitations of traditional vibration monitoring system, wireless vibration monitoring system is more needed especially for large-scale complex equipment, many measuring points, and widely distributed equipment of process industrial. According to the characteristic and demand of wireless sensor networks and vibration monitoring system, a new design method of wireless sensor network node used in equipment vibration condition monitoring was proposed. First of all, a miniature low-power sensor node for wireless vibration monitoring of equipment was developed. Then, a wireless vibration monitoring system based on wireless sensor networks was constructed. Finally, the general scheme of the system, the design ideas of node hardware and software, the strategies of wireless networking and communication as well as the monitoring software of the system are described. The results of experiment showed that the data sampled by wireless vibration monitoring node is correct, the communication of network system is accurate, and the whole system is reliable. The system therefore can be widely used in vibration monitoring of various equipment, particularly useful in electric power, metallurgy, petrochemical and other widely distributed equipments.*

***Streszczenie.** W artykule zaproponowano metodę tworzenia węzła sieci czujników bezprzewodowych, na potrzeby systemu monitorowania wibracji. Przedstawiony został sposób projektowania oraz schemat finałowego systemu, z opisem strony sprzętowej i programowej. Przedstawione wyniki badań eksperymentalnych potwierdzają skuteczność i poprawność działania. (**System monitorowania wibracji, oparty na sieci czujników bezprzewodowych**).*

Keywords: Wireless Sensor Network; Wireless Microcontroller; Data Acquisition; Vibration Monitoring System.
Słowa kluczowe: sieć czujników bezprzewodowych, mikrokontroler bezprzewodowy, akwizycja danych, system monitorowania wibracji.

Introduction

With the development of modern industrial technology, the large-scale industrial system that is made by the various machines and equipment is toward automation, high efficiency, high accuracy, whose performance and complexity are increasing[1]. Thus, more and more close relationship between the various machines and equipment make the system requirements in reliability and security have become more sophisticated. In order to meet the needs of safety and stability of equipment operation in modern large-scale industrial system, the conditions of main equipment as well as a variety of auxiliary equipment in the system need to be monitored[2]. As a result, condition monitoring system is more and more complex in construction and difficult in configuration. As we known, vibration monitoring system may be the most complex than the other condition monitoring systems. Vibration that is an important parameter of equipment operation includes a variety of useful information, and can be used for fault diagnosing[3]. But traditional vibration monitoring system connected by a lot of signal cables and thus easily mixed various kinds of interference signal is poor in the reliability of monitoring results. Moreover, the vibration monitoring system is also limited in general application because the system is complex in construct, expensive in cost, heavy in on-site installation and commissioning, poor flexibility, and difficult in maintenance[4-5]. In order to overcome the traditional vibration monitoring system for these shortcomings and achieve the large number of geographically dispersed vibration of machinery and equipment on-line monitoring, a method applying Wireless Sensor Network (WSN) technology to vibration monitoring system of machines and equipment was presented[6].

Due to the use of wireless communication, vibration monitoring system is no longer limited by the cable, which effectively solves the difficult problem of field wiring. Farther, the flexibility and scalability of wireless sensor networks make add, delete or replace any measuring node easy so that investment costs, complexity, workload of installation, commissioning, and maintenance of monitoring system are greatly reduced. The system is very suitable for remote vibration monitoring of large-scale complex structure and widely distributed equipments.

System layout

Wireless sensor networks without infrastructure is a new platform for information access combined sensor technology, embedded system technology, distributed information processing technology and wireless communication technology. WSN can real-time monitor and collect information of various objects distributed in the region covered by the networks and then send it to the host computer via a gateway node. Therefore, WSN can also detect and track complex objects located in the specified area and process these data to obtain detailed and accurate information and send to end user.

The wireless vibration monitoring network system based on WSN as shown in Fig.1 consists of sensor nodes, cluster nodes, a sink node, and a monitoring host.

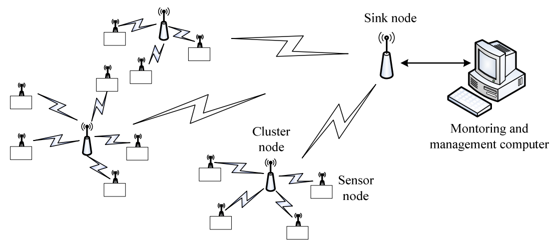

Fig.1. Layout of wireless vibration monitoring system.

Sensor nodes installed on the monitoring equipment convert and collect the status data of the equipment and transmit them via wireless communication. The system constitutes an ad hoc network in which each sensor node transmits its data collected via other sensor nodes with per-hop method. These data can reach the sink node by means of the relay of cluster node. All of sensor nodes can be divided into different clusters in accordance with the location of monitored objects. In a cluster, only one cluster node can transmit the whole data of all of sensor nodes to the sink node.

The sink node transmits all data to the monitoring host computer via a RS232 interface. After assigned by the network self-organization, some of sensor nodes become cluster nodes and act relays. Then the system can collect and control sensor nodes far away of host computer by means of relay of cluster nodes. Thus, the system is a true wireless remote monitoring system and used to monitor condition of all of equipment of widespread industrial system or product line.

In the wireless vibration network system, the host computer is a computer workstation and the wireless vibration monitoring system control center. On the one hand, it monitors and controls in real-time the dynamic network state and the working status of each node in the system. On the other hand, as a center of data management, it manages and stores the configuration of entire system, work status of node, and all collected data of monitoring equipment. It also is as a Web server to release the various data of vibration monitoring of equipment. Thus, users can browse and find the monitoring data as well as analysis results to get the working status of equipment.

Hardware of sensor node

A sensor node as shown in Fig.2 consists of sensor, Wireless Microcontroller Unit (WMU), wireless radio frequency and power supply, and so on. When used as a sink node, it includes a RS232 serial interface. The actual sensor node without box is shown in Fig.3.

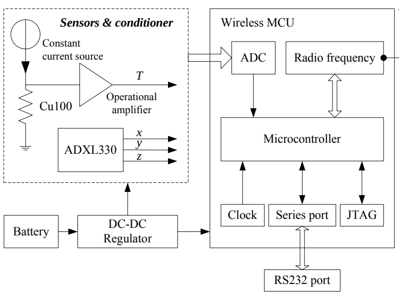

Fig.2. Functional block diagram of node.

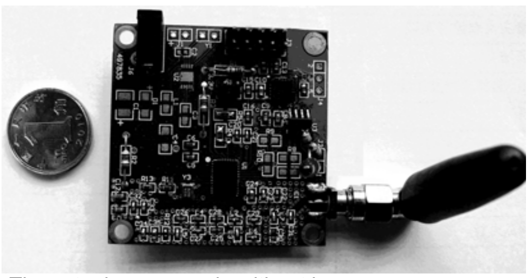

Fig.3. The actual sensor node without box.

Microprocessor and radio frequency are core components of the sensor node, which fulfill main functions such as signal sampling, data processing, wireless receiving and wireless transmitting. Considering power consumption, size, microprocessor resources, a fully integrated mixed-signal system-on-a-chip microcontroller Si1002 is employed in the system. The ultra low power Si1002 device integrates a high-speed pipelined 8051-compatible microcontroller core and a 240-960MHz EZRadioPRO transceiver [7]. Si1002 device owns 64k bytes of on-chip flash memory and 4k bytes on-chip RAM, true 10-bit 300ksps 18-channel single-ended ADC with analog multiplexer, 22 I/O ports, SMBus/I^2C, enhanced UART, and two enhanced SPI serial interfaces. Of SPI interfaces, SPI1 is dedicated for communication with the EZRadioPRO peripheral. So Si1002 could completely meet the application requirement.

Sensors in node should normally be configured according to the actual monitoring demand, such as vibration, temperature, humidity and other sensors. Moreover, taking into account the characteristics of sensor network node, it is important to pay attention to small size, low power consumption, simple peripheral circuits. The sensor node in design is configured an acceleration sensor because that main aim of the system is monitoring vibration. While a temperature sensor is also configured in the node as aid monitoring parameter. So the sensor node can be used for vibration and temperature monitoring.

A MEMS accelerometer ADXL330 made by Analog Devices Co., Ltd is used in the sensor node because that the vibration sensor based on Micro Electro-Mechanical System (MEMS) is more intelligent, more reliable, smaller in size, and lower in cost than traditional vibration sensors [8]. The accelerometer ADXL330 built-in a signal conditioning circuit is a three-axis accelerometer with small scale, little outline, low-power and analog voltage output sampled directly by Analog to Digital Converter (ADC). So it fully meets the design requirement of node.

Thermal resistance often used as temperature sensor for the case of medium and low temperature measurement. For example, copper thermal resistance is widely used because of its easy processing, low price, big coefficient of resistance to temperature, and almost linear relationship between resistance and temperature. A thermal resistance Cu100 is employed as temperature sensing element in the sensor node and applied to a constant current generated by constant current source. The different voltage at Cu100 responded to different temperatures is amplified and connected to the analog input port of microprocessor.

Software of sensor node

The software of sensor node developed using C programming language as shown in Fig.4 includes the initialization procedure, the data acquirement procedure, the radio communication procedure, and interface drivers. The initialization procedure configures the resources to be used, including the ports initialization, the ADC initialization, the SPI initialization, the EZRadioPRO initialization and so on. The data acquisition procedure carries out signal sampling, converting and saving.

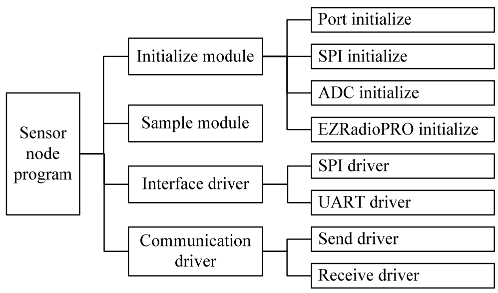

Fig.4. Block diagram of software of sensor node.

Software of monitoring management

The host computer installed with monitoring and management program is the controlling center of the whole monitoring network. The block diagram of monitoring and management program is shown in Fig.5. The program functions include: (a) configure the network and nodes, (b) communicate with the sink node, (c) periodically collect data, (d) manage the status of nodes and network, (e) renovate the network link, and (f) analyze and manage the condition data of equipment. The monitoring and management software has programmed using C++ and database. All of data of nodes, network and equipment condition are stored in a database, thus easy to be managed, inquired, analyzed, and displayed, and so on.

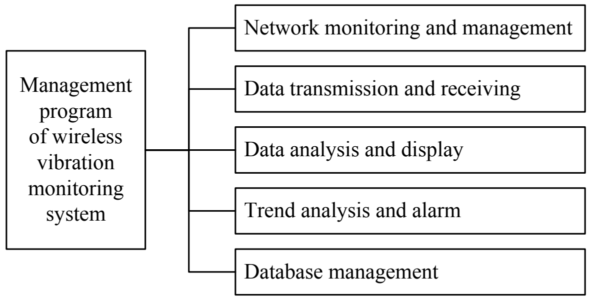

Fig.5. Block diagram of monitoring program.

Experiments

The experiments such as the basic functions of sensor nodes, and the capabilities, effectiveness and reliability of the networking and communication of the wireless system were carried out in order to verify the sensor nodes and the wireless vibration monitoring network system. The test items include: (a) the data acquisition of sensor nodes, (a) the networking of system, (c) the receiving and transmitting test of system, and (d) the distance of communication between sensor nodes. A curve of z-axis vibration as shown in Fig.6 is sampled by a sensor node installed the middle of simple support beam, which is received by wireless networks and plotted by the program of monitoring and management of host computer. The experiment results show that: (a) the system can automatically network, (b) all of sensor nodes can accurately acquire and transmit vibration and temperature, (c) the data transmission between network and sensor nodes is accurate and reliable, (d) the host computer can real-time monitor and access the status of the entire network and the monitoring data of sensor node, and (e) the monitoring program can effectively manage and analyze all of monitored data.

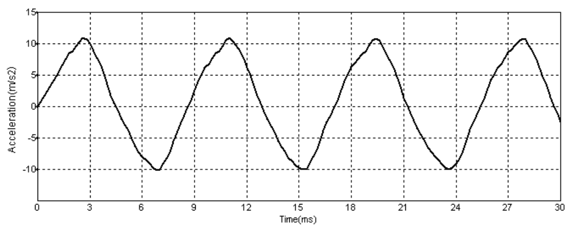

Fig.6. Waveform of vibration sampled.

Conclusions

A low-power micro wireless sensor node for vibration monitoring based on wireless sensor networks was developed. On basic of these wireless sensor nodes, a wireless vibration monitoring system of equipment were built. The system consists of sensor nodes, cluster nodes and sink node. The sensor nodes installed on the equipment acquire vibration signals send them to cluster nodes. Finally all of acquired data are uploaded to the host computer by the sink node. It is proved by experiment that the system is stable and reliable and transmission and collection of data is correct and effective. For online monitoring of industrial equipment, the system provides a low-cost, flexible and reliable solution and thus can be widely used vibration monitoring of industrial equipment in electric power, metallurgy, petrochemical, and other widely distributed case.

REFERENCES

[1] P. Ferrari, A. Flammini, D. Marioli, E. Sisinni, A. Taroni, Wired and wireless sensor networks for industrial applications. *Microelectronics Journal*, 40(2009), No.9, 1322-1336.

[2] Q. He, H. Li, Z. R. He, Remote vibration monitoring system based on CAN bus, *Journal of Vibration, Measurement & Diagnosis*, 29(2009), No.4, 398-400.

[3] F. P. Kopsaftopoulos, S. D. Fassois, Vibration based health monitoring for a lightweight truss structure: Experimental assessment of severalstatistical time series methods, *Mechanical Systems and Signal Processing*, 24(2010), No.7, 1977-1997

[4] J. Yick, B. Mukherjee, and D. Ghosal, Wireless Sensor Network Survey. *Computer Networks*. 52(2008), 12, 2292-2330.

[5] A. Vogl, T. W. Dag, and P. Storas, T. Bakke, M. M.V. Taklo, A. Thomson, L. Balgard, Design, process and characterisation of a high-performance vibration sensor for wireless condition monitoring, *Sensors and Actuators A*. 153(2009), 155-161.

[6] Q. He, K. B. Du, X. T. Zhao, D. M. Du, Acquisition and management of condition information of equipments based on wireless sensor networks, *Journal of Computational Information Systems*, 7(2011), 7, 2420-2426.

[7] Information on http: //www.silabs.com.

[8] Information on http: //www.analog.com.

Authors

Dongmei DU: corresponding author, She is now a professor in the School of Energy, Power and Mechanical Engineering at North China Electric Power University. Her interest includes Mechanical Electronic, Wireless Sensor Network. E-mail: ddongm@ncepu.edu.cn.

Qing HE. He is now a professor in the School of Energy, Power and Mechanical Engineering at North China Electric Power University. His interests include Electronic, Wireless Sensor Network, Computer and Information Technology, Measurement and Instrumentation. E-mail: hqng@163.com.