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Design of wireless vibration measuring system for material processing machinery equipment

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Design of wireless vibration measuring system for material processing machinery equipment

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Abstract: Aiming at the problem of mechanical vibration measurement in material processing equipment at present, a vibration measurement method using MEMS micro-accelerometer as measuring sensor is proposed. The wireless sensor module with the core of CC2430 device is used to form the sending and receiving node of the signal. ADS8344 chip is used as the data acquisition converter to collect the vibration signals output by MEMS sensor. Collection, storage, control and other functional modules are integrated in the single chip microcomputer. At last, the vibration peak value and frequency of the system are tested, and the feasibility of the system is verified.

Keywords: Rotating machinery; Sensor; Wireless; Vibration measurement.

1. Introduction

In the field of mechanical processing of materials, material synthesis and material transformation are inseparable from precision materials machinery equipments. There are many factors influencing the effect of material processing. The vibration of equipment is the main reason. Therefore, vibration monitoring technology is particularly important [1]. For a large number of moving and rotating devices or components, the use of new wireless sensor network monitoring mode to build wireless and distributed mechanical vibration monitoring system can make up for the deficiency of traditional wired mechanical vibration monitoring system [2]. Wireless sensor network has the characteristics of no wiring, easy deployment, network self-organization and local signal processing. So the wireless sensor network can be used to transform the traditional serial processing and centralized processing system into distributed processing [3-4] to solve the above problems.

At present, most wireless sensor network nodes have low hardware performance, poor computing and processing capacity, and are only competent for health monitoring of some structures with low vibration frequency and data acquisition requirements of slow signal such as environmental illumination and temperature [5]. For mechanical vibration monitoring, the current wireless sensor network nodes have the following deficiencies [6-8]: the resolution and sampling rate of existing node A/D converter are low. The computing speed and processing capacity of existing node processors are poor. The existing node data storage space is very small, and it is difficult to cache large amount of original data collected at high speed.

In this paper, a wireless sensor node for vibration measurement of material processing equipment is designed, and wireless sensor network is applied to mechanical vibration monitoring of material processing equipment for the first time. It solves the problems of low sampling frequency and precision, small storage capacity and limited data processing capacity.

2. Overall design

As wireless sensor network nodes are small in size and usually carry batteries with very limited energy. The processor module, as the core module of the node, is very important in its low-power characteristics. Therefore, the node adopts the structure of microcontroller and CC2430 wireless transceiver module. The node is mainly composed of microprocessor board, data acquisition board, programming and debugging interface board, radio frequency board and sensor board. In the hardware design, different monitoring objects and monitoring modes have been fully considered for different hardware requirements. The hardware design has adopted the design idea of modularization and replaceable combination. It is convenient for users to select suitable hardware combination scheme according to the requirement and cost of monitoring object. Fig.1 is the block diagram of node circuit functional modules. The traditional piezoelectric acceleration sensor has excellent performance in terms of frequency response and linearity, etc. However, the general piezoelectric acceleration sensor requires a power supply voltage of around 12-24v, which is not suitable for use in low-power systems. At the same time, some models also need to be equipped with preamplifier, and circuit modules increase. Compared with piezoelectric sensor, low price and small size MEMS acceleration sensor shows great advantage in wireless sensor. MEMS acceleration sensor is used in this node design, and interface with traditional sensor is reserved. For the module of analog to digital conversion, considering processor performance, node cost, storage capacity and other aspects, the 16-bit ADS8344 A/D converter with synchronous communication interface of ADI was adopted. In order to satisfy high-speed and high-precision data acquisition, a mass storage system with SD card as the storage medium was designed for the node.

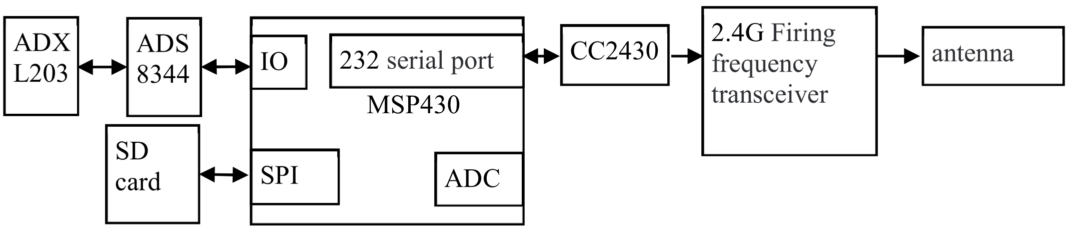


Fig.1 Overall structure diagram of wireless nodes

3. Sensor acquisition circuit design

The ADXL203 is a complete high-precision, low-power, single-axis/two-axis accelerometer that provides voltage output adjusted by the signal. All functions are integrated into a single chip IC. The full range of acceleration measurements for these devices is $\pm 1.7g$, $\pm 5g$ or $\pm 18g$. Dynamic acceleration such as vibration and static acceleration such as gravity can be measured simultaneously. Typical background noise is $110\mu g/\sqrt{Hz}$. So in the application of tilt detection, narrow bandwidth is available and analysis $1mg$ (0.06° incline). Analog sensor output for most applications, a single capacitor C_{DC} ($0.1\mu F$) can be sufficiently decoupled from the accelerometer and thus eliminating power source noise. The ADXL203 internal structure diagram is shown in Fig.2 and circuit diagram is shown in Fig.3.

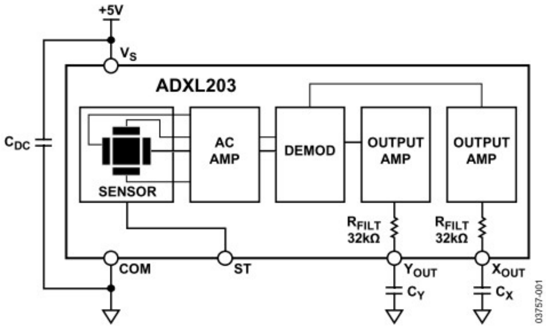


Fig.2 ADXL203 internal structure diagram

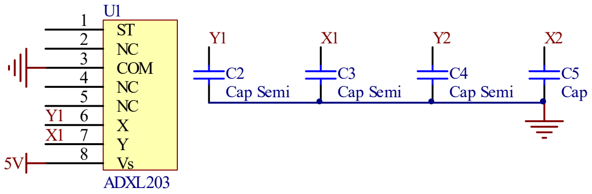


Fig. 3 Sensor circuit diagram

4. Wireless communication module design

This node adopts the low-power radio frequency chip CC2430 of 2.4GHz frequency band as the wireless communication module. It runs the communication protocol independently and exchanges data and commands with CPU through the serial port and GPIO. This modular design not only reduces the burden of the master controller but also enhances the flexibility of different hardware modules. The node adopts ZigBee wireless communication protocol to realize node networking and data transmission. It uses the physical layer (PHY) and data link layer (MAC) defined by IEEE802.15.4, and defines the network layer (NWK) and application layer (APL) architecture on this basis. This paper develops a wireless sensor network node control program suitable for data acquisition and transmission control in its application layer. Node can be divided into base station node, routing node and terminal node in network function. The base station node is operated by the coordinator in Zigbee network. It is the first device in the network. When it starts, it first scans the physical channel, determines whether the network exists on the channel and records its signal intensity. When all channel scans are completed, it selects a channel with the least signal strength to set up the network, and selects the network identifier (PANID). At last it waits for other nodes to join the network. When other child nodes request to join the network, the base station node will assign a unique 16-bit network address in PAN to the child node according to the node type and address allocation algorithm. The routing node's role is to relay the packets, allow other nodes to join themselves as children, and is responsible for assigning network addresses to the children. When the router starts, it first scans the channel to find the existing network and selects a base station node with the highest signal strength to send a join request. The terminal node can only join the network of other routing nodes or base station nodes and can only communicate with its parent node. The terminal node can turn off the radio frequency circuit when there is no data sent or received, so that its power consumption reaches the minimum.

In this paper, the base station node is connected to the computer through the USB interface. The network will be established automatically after it is powered on, and waites for the terminal node to join. When the terminal node and the base station node constitute the network, all terminal nodes can use the base station node and the upper computer data acquisition software to exchange data and command packets. After the upper computer starts the collection task, the base station node first synchronizes the time of all the collection terminal nodes and then releases the collection task to them. The terminal node can cache the collected data in SD memory card and submit the data to the upper computer software after the upper computer starts the data reading task.

5. Conversion module design of ADS

The ADS8344 is an 8-channel, 16-bit successive approximation A/D converter with synchronous communication interface. The power consumption under the 5V power supply and the sampling rate of 100 kHz is only 10 mW. The reference voltage V_{REF} range from 500 mV to VCC. The input voltage range for each simulated channel correspondingly is 0V to V_{REF}. A single power supply of 2.7V-5 V is adopted, and power loss mode can reduce the power consumption to 15 μW. Low power consumption, high speed and in-chip multiplexer make the ADS8344 an ideal choice for battery power system. The eight analog input channels of the ADS8344 can be configured as single-ended input or differential input, with an output sensitivity of 16 mV/g at a working voltage of 3.3v. The ADS8344 reference voltage USES precision stabilized REF3120 with an output of 2.048 V. The small size, low power and low pressure drop of REF3120 makes it very suitable for portable and battery-powered systems. REF3120 is stable for any capacitive load.

6. Software design

The system adopts multi-cluster tree topology and hierarchical routing protocol. The wireless sensor node adopts the design of dual processor. The MSP430 processor interacts with the radio frequency module CC2430 through a serial port, including the vibration data of MSP430 and the control instructions received by the wireless module CC2430. Two programs are defined in the wireless module. One is responsible for sending and receiving wireless messages, mainly including receiving command messages sent from the terminal node and sending data to the monitoring terminal. The other is responsible for MSP430 chip communication, mainly through the serial port to issue control commands and receive data collected from the serial port. The two application objects interact through the message mechanism and cooperate to complete the program functions on the node. The MSP430 chip is mainly capable of data collection and storage. It operates according to the command of the master controller chip and sends the data to the master control chip after the collection is completed. The vibration signal collection process is shown in Fig.4.

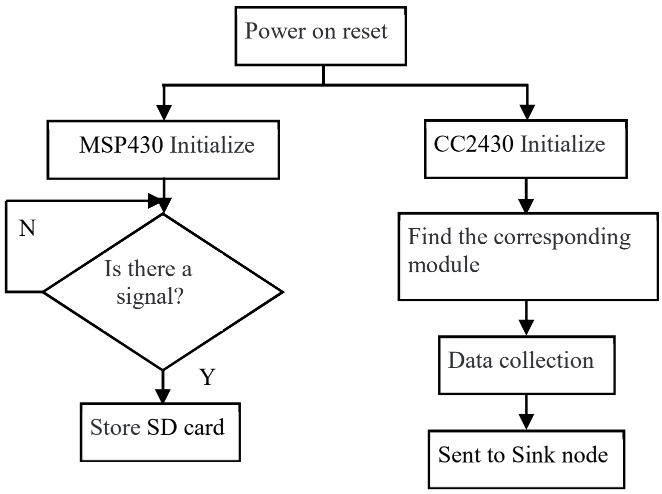


Fig.4 Software flow chart

7. Experiments and data analysis

7.1. Signal acquisition accuracy tests

The test system platform is shown in Fig.5. For the convenience of hardware debugging, MSP430 MCU control board adopts professional integrated board with good anti-interference. Powered by two 3.7V 18650 lithium batteries, the MCU is powered by the on-board 7805 and AMS1117 chips down to 3.3 . The average current measured when all modules are working is 124mA, while the average current when the data acquisition and storage module is turned off is only 35 mA when the wireless connection is kept.

In order to test the accuracy of sensor vibration signal collection, the sensor node and the taike MDO3000 series oscilloscope are used to simultaneously collect the peak value of a vibration signal. 10 sets of readings are taken as the average value for each signal. Taking the TAIKE oscilloscope as the standard, the measurement results are verified, such as Tab.1, with the maximum error not exceeding 0.0004V.

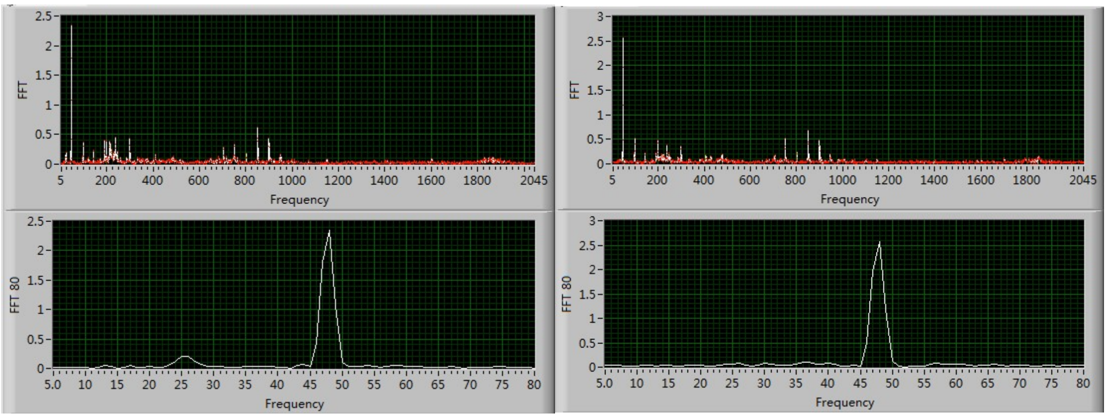
Fig.5 Experimental rig

Table.1 Comparison of vibration peak data

Test point	MDO3000	Error	Relative error
1.18775	1.18742	0.00033	0.0278%
1.57954	1.57942	0.00012	0.0076%
1.98721	1.98745	-0.00024	0.0121%
2.12365	2.12401	-0.00036	0.0169%
2.35619	2.35629	-0.0001	0.0042%
2.58973	2.58988	-0.00015	0.0057%

7.2. Vibration signal frequency comparison tests

Two terminal nodes and 1 base station node are used to form a monitoring network to monitor the vibration of a driving test bed. Two MEMS sensor plates are respectively fixed on the bearing seat and motor enclosure of the driving system. The output signal of ADXL203 acceleration sensor of node 1 was compared with that of NI piezoelectric acceleration vibration test acquisition card NI-9232. The motor speed is set to 1480 r/min , the sampling frequency of both the node and the acquisition card is set to 1024Hz, the collection length is 4096 points, and the original data file collected by the node is cached in the SD card. ADXL203 sensor nodes of the output signal spectrum analysis is shown in Fig.6 (a). Take the radial acceleration signal of the bearing acquired by node 1 and carry out the spectral analysis. The analysis length is 4096 and the Blackman window. The results are shown in Fig.6 (b). The frequency and amplitude of the main spectral line were read for comparison. It can be seen that the frequency of the main spectral line of the node and the acceleration signal collected by NI-9232 is consistent in the range of (0-2048) Hz, and the amplitude error is small, indicating that the node can collect the mechanical vibration signal of higher frequency.



(a) Acquisition and analysis results of NI-9232 (b) Vibration node data analysis results

Fig.6 Comparison of vibration measurement results

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8. Summary
A measuring system for vibration signal acquisition of material processing equipment is designed in this paper. The system adopts advanced MEMS sensor as the measuring element, which has the advantages of good temperature stability and high linearity, and is an important development hotspot of intelligent measuring sensor in the future. The design method of the high-performance wireless sensor network node of the measuring system is introduced in the aspects of sensor design, wireless node design, data acquisition module design and transmission. The experiment table of motor frequency vibration is built, and the measurement software of the upper computer is designed by using virtual instrument technology. The performance of sensor and wireless communication node is verified through comparison experiment. The results show that the node can be competent for accurate high-speed acquisition and storage analysis of mechanical vibration signals.

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