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RESEARCH ARTICLE

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Wireless sensing experiments for structural vibration monitoring of offshore platform

Abstract In order to validate the feasibility of applying wireless sensing technique to structural monitoring of offshore platform, the experiment of wireless sensor network on offshore platform is presented in this paper. First, wireless sensor network and its topology structure is put forward, and the design of sensor nodes, base station, communication protocol is discussed according to self-developed wireless sensor network. Second, true offshore platform and its experimental model are introduced. Finally, wireless sensing experiment for offshore platform structure is completed and the analysis of the experimental result is given. The research shows that wireless sensor network applied to offshore platform can reflect the vibration of the structure; the sensor nodes are fixed and removed expediently, which saves the cost of signal line as well as installation time.

Keywords wireless sensor, offshore platform, acceleration, structural monitoring

1 Introduction

As an important establishment for petroleum exploration, offshore platform also is a base for working and living on the sea. However, offshore platform structures are damaged by seawater corrosion, ocean wave, tide, ocean current, drift ice, earthquake, sand and halobios. Consequently, its resistance to reduction is obvious, which may results in accidents. All these side effects inevitably produce such problems as financial loss, personnel casualty, environmental pollution and political impact [1]. To improve the reliability of offshore platform, structural monitoring and evaluation have been an important research topic.

In a structural monitoring system of an offshore platform, many environmental stimulants that affect the offshore platform are considered. The structural parameters are gathered by mounted sensors, then collected data are processed by intelligent algorithms, and the structural status and corresponding maintenance measures are proposed [2]. In this system, gathering structure information by using sensor arrays for maximizing the response of the structure is the base of structural health monitoring (SHM). Usually, wired sensing network is a main connection mode for structural monitoring, but for an offshore platform it needs plenty of wire (i.e., 27000 m line are needed for the monitoring of CB32A offshore platform in Shengli Oil Field, China), which makes it difficult to find out broken-down location while there is something wrong with the sensors or lines. Moreover, high costs of material and maintenance are needed. However, with the development of technologies in sensing, wireless communication and micro electro mechanical systems (MEMS), wireless sensor network has been developing and being gradually applied in the SHM for civil engineering structures to lower the capital associated with wire-based structural monitoring systems. In this paper, a kind of wireless sensor network is developed, and structural vibration of Bohai Sea JZ20-2MUQ offshore platform is monitored using the designed network.

2 Wireless sensor networks

As an interdiscipline consisting of sensor, communication and wireless technology, the wireless sensor network is initially applied in the military and then extended to environmental monitoring, agriculture, medical treatment and civil engineering [3–6].

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For the wireless sensor network to be applied to the structure monitoring of an offshore platform, we adopt a star topology structure [7], which means that a base station manages all wireless sensor nodes. The network topology structure is described in Fig. 1. Made up of computer connection with wireless transceiver, the base station performs such tasks as controlling all wireless sensors' operations and processing data using software in the computer. Integrating sensors of temperature, acceleration, buzzer and light, every wireless sensor node could monitor the temperature and acceleration of structures, set the reference value of acceleration according to the surrounding temperature and then finish the fusion of temperature and acceleration. Besides, the wireless sensor could give acceleration limit value to perform the alarm function using the buzzer.

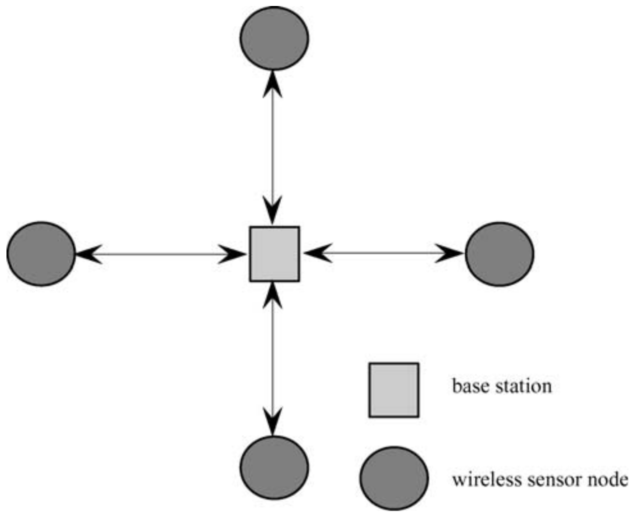

Fig. 1 Star topology structure of wireless sensor network

2.1 Wireless sensor node

Based on existing MEMS and embedded techniques, a wireless sensor is constructed by integrating several modules: a detection unit, a microprocessor unit, a wireless transceiver and a power unit. Specifically, hardware modules of wireless sensor are shown in Fig. 2 [8]. In Fig. 2, the detection unit consists of sensing units and their attached circuits, which could get parameter data of the tested structures. Microprocessor unit collects and pre-processes signals sensed by the detection unit to obtain more accurate data, and it also controls transmitting the data. As a transmission medium between all wireless sensor nodes and the base station, wireless transceiver is in charge of receiving and sending data in the wireless mode. The power unit using lithium battery provides energy for the above units.

The wireless sensor node is designed by modularization. Two printed circuit boards are developed: one is sensing and processing board, including the detection unit and the microprocessor, another is wireless communication board.

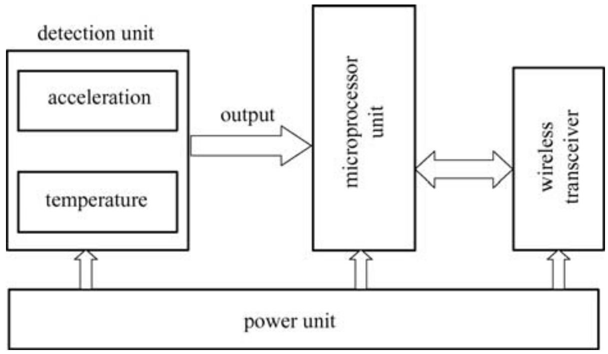

Fig. 2 Modules of wireless acceleration sensor

2.1.1 Sensing and processing board

The sensing and processing board consists of an accelerometer, a thermometer and a micro-processing unit. For the accelerometer, ADXL202 is selected as it is a low power, low cost fully functional 2-axis accelerometer. It is a surface micro-machined polysilicon structure built on top of a silicon wafer. Since offshore platform structures have low natural frequencies, a bandwidth of 50 Hz will be sufficient for measuring their dynamic responses in practical applications. The noise level is 1.8 mg. For the temperature meter, we use TC1047 chip with low-power consumption and a low voltage between 2.7 and 4.4 V. One advantage of the TC1047 is the linear relationship between the voltage output and the measured temperature, making it ideal for applications.

The micro-processing unit on the sensing and processing board could gather, pre-process the analog and digital output from the detection unit. It could also exchange data with the wireless transceiver. The micro-processing unit used in this design is an Atmega8 chip, which integrates a large storage memory and interface circuits. As a low-cost microprocessor, the chip adopts a small pin package. It is characterized as 8 bit high performance, low cost AVR micro-controller with advanced RISC instruction aggregation, many powerful external interface circuits, and five sleep modes, including idle, ADC noise reduction, power-save, power-down, and standby. Besides, sensing and processing the board integrates also other devices: two lights for indicating the working status of the wireless sensor, micro-sounder for making an alarm while in a abnormal working status.

2.1.2 Wireless communication board

Wireless communication board is used to transmit data measured by sensors to the computer by the wireless mode, consisting of wireless transceiver, antenna and some components used for increasing the signal intension and sensitivity. The wireless communication board is developed on the basis of CC1000, a true single-chip RF transceiver with an ultra-high frequency range and low power requirement. The CC1000 circuit is mainly used for industrial, scientific and medical (ISM) instruments. The transmission distance is usually about 150 m. The FSK data transmission rate of CC1000 is up to 76.8 kBaud. In this design, CC1000 FSK data rate is designed to 9.6 kBaud and a high-gained antenna is used for increasing the transmission distance. These characteristics of CC1000 meet data transmission requirement in the SHM for offshore platform structures.

2.2 Base station

The base station as the network control center is constituted by the wireless communication board connected with a standard PC interface. The base station monitors for correct operation of overall wireless network and collects data for every wireless sensor node.

2.3 Communication protocol

The communication protocol of wireless sensor network guarantees reliable network communication and stable operation. Because the base station and each node work at the same frequency band, there is only one node that can communicate with the base station at the same time, otherwise there would occur conflicts or network error. To avoid the co-frequency interference, time-sharing TDMA technology is adopted in this network [9]. The communication data quantity is changeable at different time because the data collected by each node in the system is random. If taking the equal time division mode, there will occur an imbalance of each channel data transmission and waste of time interspaces. While wireless communication connection can be achieved in the network system when the base station has data requirement for a certain node, and for other time the base station and the node may not be connected. Therefore, this paper adopts the token TDMA: each wireless sensor node is commonly idle, and the base station may monitor the status of each node. When the base station has data requirement for a certain monitoring node, the corresponding node is granted and wireless communication connection is built. Consequently, when the base station communicates with one node at a time, the network structure communication mode is changed form the point-to-multipoints communication mode to multi-point-to-point communication mode [10].

3 Offshore platform model and its wireless vibration monitoring

The wireless sensor network test is completed on the offshore platform model of Bohai Sea JZ20-2MUQ.

3.1 JZ20-2MUQ offshore platform

The offshore platform of Bohai Sea JZ20-2MUQ is a pipe living and power platform, which is designed, fabricated, and installed in China. The platform is located in the north of Liaodong Bay where there exits the most serious sea ice and the extensive intensity of resisting earthquake is designed to 8 degree. It can work at a depth of 15.5 m. The offshore platform consists of three modules: the top module used for living is made up of three-layer steel frame structure; its middle module used for equipments is made up of two-layer steel frame structure; its bottom module used for important supporting parts is made up of pipe frame structure. The pipe frame structure including four crura pegs looks like square quadrangle. At the underwater part of the pipe frame structure, there are some crossing inclined supports to prevent sideward movement. The part of the pipe frame structure above the surface is divided into two levels whose elevation is about EL+5.850 m and 10.00 m respectively. There are no inclined supports to decrease the ice load between the location of EL−3.500 m and the location of EL+5.850 m.

3.2 JZ20-2MUQ offshore platform model and vibration monitoring experiment

The ratio of the experimental model and the true offshore platform is 1/10. A wireless sensing test is performed to monitor the vibration acceleration of this model in different push ice and bend ice, and two wireless sensor nodes are put respectively on the location of 2.5, 2.85 of this model. The location of the ice load selected is at the height of 3 m above the ground, and this means that the location corresponds to that of the ice loading of the offshore platform.

The two placed wireless sensor nodes and the base station compose a wireless sensor network for structural health monitoring of the offshore platform. In this experiment, the sample rate is 20 Hz. As referenced sensors, wired acceleration sensors are also located at the corresponding place to validate the designed wireless sensor.

3.3 Experimental results and energy analysis

The time histories and the power spectral density $a(\omega)$ of the wireless sensors and corresponding wired sensors are depicted in Fig. 3. Although minor differences are present in time histories, they agree well. As for power spectral density $a(\omega)$, the peak frequency of the wireless sensor is 3.1154 Hz, while that of the wired sensor is 3.0127 Hz, the error is $\mathrm{Err}_f = (3.1154 - 3.0127) \div 3.0127 \times 100\% = 3.4\%$; the peak power spectral density (PSD) value of the wireless sensor is 244.2359, and that of the wired sensor is 255.9653, the error is $\mathrm{Err}_p = (255.9653 - 244.2359) \div 255.9653 \times 100\% = 4.6\%$. All the small differences meet the requirement for the SHM for offshore platform, and the designed wireless sensor can monitor true structural vibration.

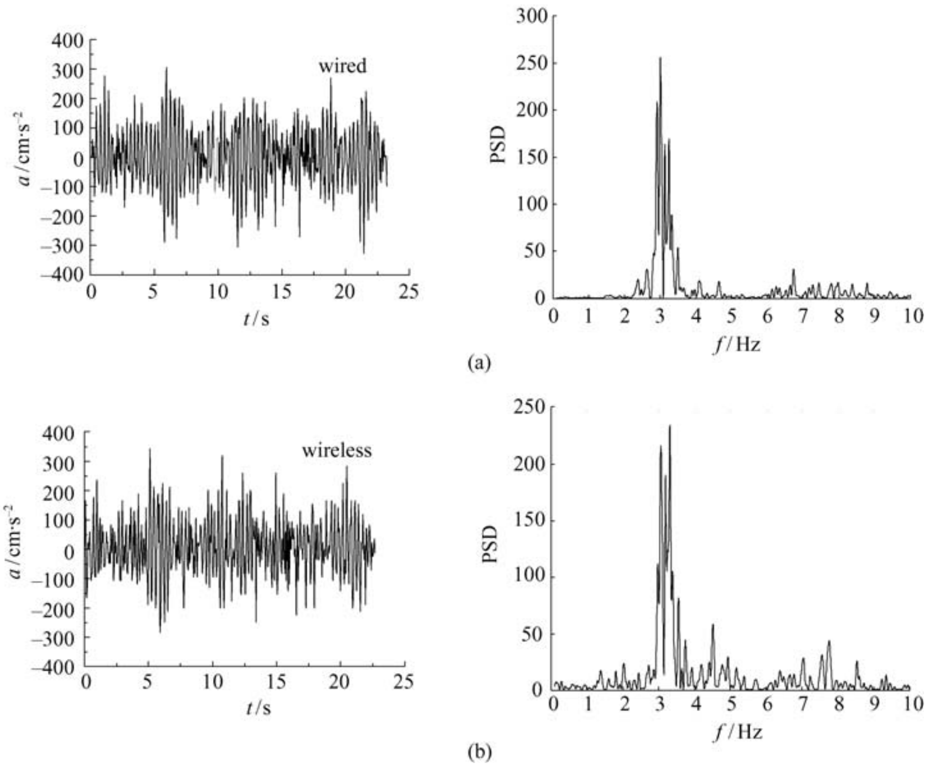

Fig. 3 Graphics of acceleration collected by wireless and wired sensor in operating mode. (a) Wired sensor; (b) wireless sensor

It is a basis guarantee for structural monitoring to sample continuously. In the present research, lithium battery used as power unit has the characters of 600 mAh and 3.6 V. The current of the wireless sensor is $I_w = I_m + I_a + I_c = 3.6\ \text{mA} + 1\ \text{mA} + 10\ \text{mA} = 14.6\ \text{mA}$ while it is collecting and transceiving data, and the sensor node could work for about 41 h in this mode. The current of the wireless sensor is $I_{idle} = I_m + I_a + I_c = 0.5\ \mu\text{A} + 0\ \text{mA} + 92\ \mu\text{A} = 92.5\ \mu\text{A}$ while it is idle, and the sensor node could work for about 270 d in this mode.

4 Conclusions

Based on the experiments and simulation results, the following conclusions can be drawn:

1) The sensor nodes are fixed and removed expediently.

2) The sensor is cheap and could save costs.

3) The wireless sensor network works not needed line, which can save installing time.

The wireless sensor network designed for structural health monitoring of offshore platform structures is feasible. But there are some problems such as waterproof and reliability. The design is preliminary and the improvement is necessary. In general, the wireless sensor network for structural health monitoring of offshore platform has good foreground.

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