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The Design of Densely Measured Points Long-term Monitoring System Based on Wireless Sensor Network

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Abstract. The wireless sensor network is a highly active area of research. Much progress has been made in wireless sensor network research for structural monitoring, but the research of the long-term monitoring system based on wireless sensor network in civil engineering structures is still at the beginning stage. The paper proposed to use wireless sensor network to realize intensive measurement long-term monitoring, in order to improve the effect of structural health monitoring. It introduced the characteristics and deficiencies of the wireless technology application in the structure health monitoring system, and proposed the system design principle of the densely measured points long-term monitoring system based on wireless sensor network. We has carried on the detailed argumentation and design from system architecture, the terminal node, monitoring method three aspects, and put forward a set of solutions.

Introduction

Since 1980s, countries in the world have already arranged structural health monitoring system(SHMS),the method of SHMS and damage detection have gained more and more attention by engineering world, this causes SHMS to be an emerging discipline.

In recent years, the research and application of SHMS based on the measurement of dynamic information have made significant progress, various types of sensors have been emerging in an endless stream, software and hardware system of on-line monitoring is perfect with each passing day, the damage identification theory based on the dynamic measurement has also made great progress. With the in-depth study and a large number of engineering practices, researchers generally found that sensor location has a great relevance with the damage detection results[1]. Some literature points that damage is essentially a local phenomenon. Sensors near the damage position can obtain more damage information than other sensors. Therefore, the sensors must be densely distributed in the structure[2].

Using densely measured points method, the biggest characteristic is to improve the sensor disposition density rather than improve single sensor capability. Due to the wide distribution of sensor, wiring difficulty and cost is an outstanding issue when applying SHM system in large engineering structures. The use of wire system in densely measured points condition is a very difficult task.

The Appearance of Wireless sensor networks offers the possibility for such applications. Wireless Sensor Networks (WSN) is a multidisciplinary technology developed recent years, which is considered to be one of technology which have a significant effect on the 21st Century.it consist of a large number of cheap micro sensor in the monitoring region, forming a multi-hop self-organized network system through wireless communication, which aim is to collaborate to percept, collect and process object information in network coverage area, and send it to observers.

Application of Previous

On 1996, the wireless sensor was applied in bridge monitoring by Kenneth Maser for the first time[3], from then on, the attention of wireless sensor networks in the health monitoring began to warm up. The researchers generally thought that the wireless system is the development direction in the future, and proposed the Modular Wireless Modular Monitoring System concept. With the rapid development of wireless technology, wireless sensor monitoring system is more and more applied,

but has no big breakthrough in the application ways, just simply simplify the long distance wiring work. The truly application of wireless sensor networks based on monitoring system, is applied only to get the pilot application in some temporary monitoring projects[4].

At present, the use of wireless technology in the long-term monitoring system has the following characteristics: (1) The combination of wireless node and vibration sensor is the most common.(2) The quantity of wireless node is little, can not reach the level of intensive monitoring.(3) Subject to the node power consumption, the wireless nodes in long-term monitoring system are connected to the power, and not battery power supply.

The author believes that the following reasons restrict the application of WSN in SHM. (1) The energy consumption of wireless node. The effort of reducing the wireless node energy consumption has been continuing, but still does not reach the desired degree. On the other hand, the research progress of improving polymer battery energy density is slow,(such as Isotope battery, solar cell, self-electric chips and other long-life battery.) Therefore, in the circumstances of long-term monitoring, the wireless node must have the power supply, is not the truly WSN. (2) The measurement of vibration signal needs strictly synchronizes with wireless sensor network. The Transmission of vibration signal needs high network bandwidth. It would increase the node hardware requirements if distributed processing is used. (3) The monitoring method based on vibration signal demands not high to the number of sensors, can not reflect the advantages of WSN in intensive monitoring.

System Design

Civil engineering structure is large, complex, more covering and the service time is long. It is a challenging task to achieve intensive measurement for long-term monitoring in such a structure .Our goal is to design a kind of wireless health monitoring system of high density, low cost and long service life to solve this problem. It includes two aspects, one set of hardware system with long life wireless nodes and one set of low power consumption monitoring method.

Principles of Design

When we use the wireless system to achieve long-term monitoring in a structure which needs service for decades or even centuries, its wireless node must have exceptional service life, thus low power dispassion is the most important principle in the whole system design. The large size of the structure makes the space and quantity of sensors arranged on the structure very big, this requires the hardware system has larger transmission distance and stronger anti-jamming capabilities, thus having higher requirements for data transmission of the master nodes.

On the other hand, civil engineering structure monitoring location and content can be defined at the beginning of the system design. It does not require intelligent self-organizing network. In addition,civil engineering structure have more or less electric power line providing the basic functions of lighting, ventilation and anticollision, thus a part of the sensor nodes arranging on the structure can get the power supply, battery is not the only way. These factors then provide favorable conditions to the system design.

These factors determine the characteristics of wireless sensor network applied on the civil engineering structure. (1)Simple function, low power consumption, stronger adaptability to the environment, working as long as possible, this is the first goal of the sensor node design. (2)Using a clear organizational structure network form, dividing monitoring area according to the type characteristics of the structure.(3)Sink Node requires higher bandwidth, a certain data storage and computation ability, to adapt to the distributed computing.(4)In order to extend the service life of the system, redundant sensor nodes can be laid at important measure points.

3.2 Selection of Network Framework

Each unit of wireless sensor network is formed by self-organizing network, which is an important research content of the wireless sensor network technology. The premise of research and development of self-organizing network technology is that all sensor nodes is randomly distributed in

the monitoring area. This have clear distinction with the civil engineering structure monitoring tasks, so there is no need to use self-organizing network function, it can not only simplify the network protocol, but also can reduce hardware requirements, and make the energy of node orderly and controllable. For our purposes, it is reasonable scheme to plan network layout based on the measured object structure shape and a predetermined distribution of monitoring points.

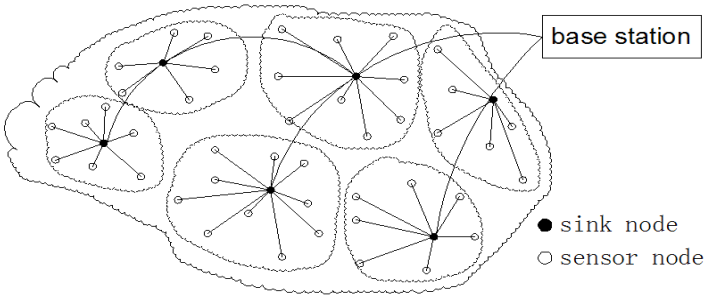

Fig. 1 Network Topology Structure

Network topology structure is presented in Fig.1.According to the structure characteristics to divide monitoring region and set regional sink nodes, sink nodes need to choose at the position which can easily connected power line. The sensor nodes in the region are only connected to the corresponding regional sink nodes. Because of connecting with monitoring center, sink node has higher bandwidth, which ensure the timely transmission of regional information. The network structure has the advantage of easily dividing the network, reducing the requirements of the sensor node communication and computing as far as possible, also avoiding the communication interference and collision problem of a large number of nodes.

The monitoring system is composed of a large number of wireless sensor,its operation process is shown in Figure 2.The sensor node performs only a simple data processing, such as averaging, summation and so on. In order to ensure the continuity of acquisition, it is designed into a non-initialization work mode.Sink node sent the data to the monitoring center after fusion, it can significantly reduce the communication time, reduce power consumption, improve efficiency. Regional division of the monitoring and the arrangement of the monitoring center should ensure that the sink node can communicate less.

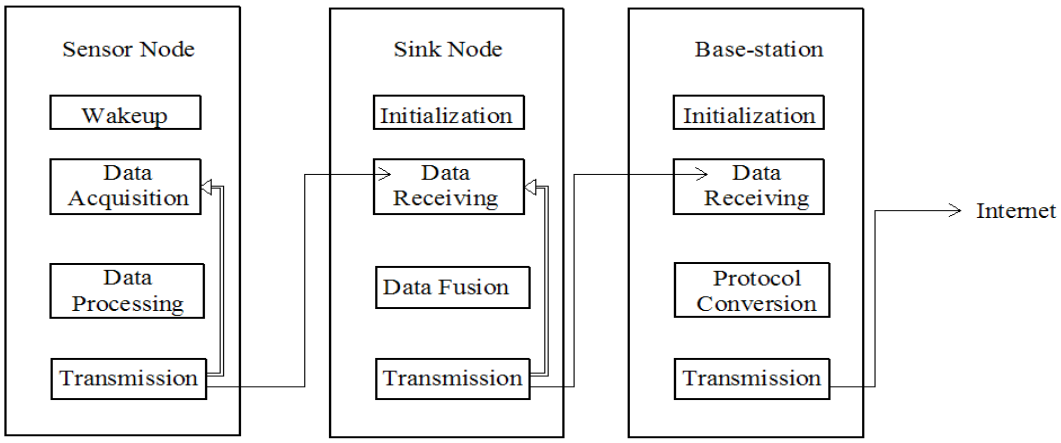

Fig. 2 Operation Process of the System

3.3 Node Design

A large number of sensor nodes use a battery as a power supply, in order to extend the node lifetime, we must use the ultra low power communication protocol. In the international standard of the short distance wireless communication protocol, RuBee protocol, Bluetooth low energy4.0 protocol is the lowest power consumption.

From a technical view, RuBee work at 132 kHz, it is particularly suitable for harsh environment, it can also work normally in the water and metal occasions, the effective transmission distance is 3-30 meters, the label life of RUBEE is up to 10 years using a standard lithium battery. When the RuBee protocol used in sensor networks, the node power consumption is also satisfactory. The defects are that low frequency leads a low bandwidth, and data transmission speed is slow, moreover there is a conflict between sensor nodes. Currently it is not common to use RuBee protocol SOC (System on Chip). Therefore the difficulty of the development is high.

Bluetooth 4.0 LE (Bluetooth 4.0 low energy) work at 2.4GHz, the maximum data rate is 1Mb/s, usually using in a distance of 50m, extremely low power node lifetime is up to two years or more. The wireless Scheme Specifically for a higher requirements of the cost and power consumption makes it possible that the Bluetooth technology can be used in intelligent instrument, sensor network, networking and other fields. Although power consumption is higher than RuBee, but Bluetooth 4.0 LE has received recognition from more people for its superior performance and mature development kit.

Based on Bluetooth 4.0LE, The SOC has many solutions, such as Ti's CC2540, it integrated RF module, MCU (microprocessor control unit) module and abundant peripheral interfaces. A sensor node composition is presented in Fig. 3. The sensor node design based on the CC2540, can reduce the design difficulty, reduce cost and improve product stability.

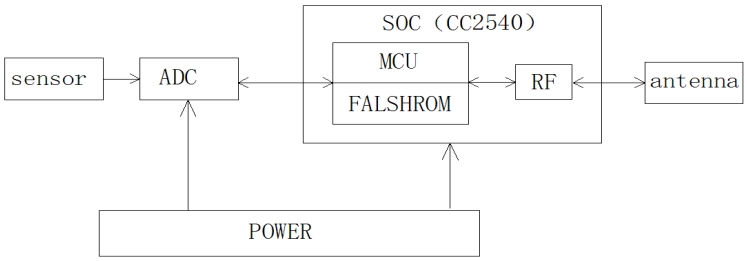

Fig.3 Sensor Nodes Composition

In addition to the Bluetooth 4.0RF module of the sensors nodes to connect sink node, it also need a second set of RF module to connect to other sink nodes and monitoring center. Because the sink nodes have a continuous power supply, the task of testing vibration signal can be placed at the sink node. For the second set of RF module of sink node, the selection criteria should be high bandwidth, long distance. There are many protocol with the target of high bandwidth, long distance, the most mature one is the WiFi protocol among them. The sink node is presented in Figure 4.

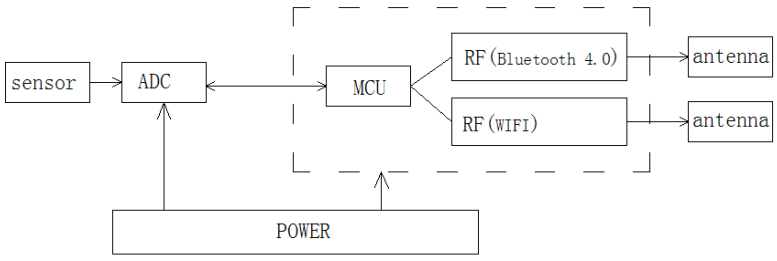

Fig.4 Sink Nodes Composition

3.4 Monitoring Method

In the previously mentioned monitoring system, sensor nodes acquire static measurement data after connecting sensor, and the sensor obtaining the dynamic measurement data is directly connected with sink nodes. The available static measurement data on structure monitoring is static stress and strain, static deformation, temperature, load pressure; dynamic measurement data is speed, acceleration etc.

The reason for this is, for any wireless equipment, energy consumption is proportional to the amount of network data. In the case of continuous high intensity data transmission, the using time will be greatly reduced, the transmission of dynamic signal of wireless sensor node can only work for several hours in using of battery-power.

From the view of enhancing energy module, present chemical battery whose energy density is very short can not improve greatly, the performance and price of isotope battery and solar battery can't meet the requirements. Besides the use of a better hardware system which needs lower power consumption, the change of monitoring approach can also extend node lifetime. Dynamic measurement is of large amount of data and needs long measuring time, so it inevitably brings about the high load of network transmission. Due to a long time interval and small amount of data, static measurement is very suitable for coordination of wireless sensor networks. Under the same hardware conditions ,we make the comparison test, the sampling rate down from 1 times per second to two times per minute, the average current consumption is reduced by 50 times, theoretical node lifetime increases by 60 times.

If the change of the structural properties results from unexpected events (such as seismic load or strong wind load), and the time the sudden factors acting on the structure is short, when it ends, through the static measurement we can find the influence the unexpected events resulted on structure. If the change of the structure characteristics is the reason of the factors of component's corrosion and other slow long-term factors, then hourly data acquisition is enough to deal with this situation.

Based on this idea, we designed such a routine monitoring mode. The sensor node collects a set of data per hour, then we obtain an average value before saving it. If every collection value doesn't exceed the preset safety limits, after the test data is full, we sent it to the sink node at a time. If the collected values exceed the safety limits, it sends the alarm signal to the sink node, then all sensor nodes in the control area start work and improve the collection frequency to10 times per minute, it will pay sustainedly attention on the area until the alarm is released.

4. Conclusion

Wireless sensor network is a promising technology, it is not only a kind of monitoring technology, but also a kind of monitoring idea. The monitoring scheme and hardware equipment based on the traditional dynamic measurement is not suitable for dense sensor monitoring system, using wireless sensor network is the inevitable trend of the SHM system's future development.

The greatest difficulty of using the WSN technology in the long-term monitoring system is the node lifetime is too short. To change this situation, we must use low power hardware and low energy consumption monitoring model. In this paper, combining with the civil engineering structure features, we presents the principle of the system design. Through planning of network topology, designing ultra low power node hardware, Establishment of the low power consumption monitoring mode, we form a complete set of solutions.

The wireless sensor network is a highly active area of research.The densely measured points long-term monitoring system based on wireless sensor network will be more perfect in the future.

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