Study on Structural Health Monitoring and Damage Detection in the Field of Civil Engineering

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Abstract. Structural health monitoring and damage detection can help people avoid emergency casualties and take preventive measures, and it is very important in practical application. After consulting authoritative information, the structural health often affected by the surrounding environmental safety factors and structural safety factors. This paper begins with the harm of the inadequate building safety and the factors affecting building safety. To detect structural health problems and avoid many kinds of disasters, three monitoring methods have been mentioned, two new building safety detection methods and a damage detection scheme, called wireless sensor network subsystem, global navigation satellite system technology, and ultrasonic flaw detection technology. The principles of three methods are mainly expounded, and their advantages and disadvantages are analyzed, by putting forward suggestions for future research prospects and giving some practical examples. Finally, it is concluded that wireless sensor network method is simple to achieve but the monitoring data is single; GNSS system has high precision but cannot be widely used; And ultrasonic flaw detection technology can detect steel damage single efficiency.

Keywords: Structural Health Monitoring, Damage Detection, Wireless sensor network subsystem, Global Navigation Satellite System Technology, Ultrasonic Flaw Detection Technology.

1. Introduction

In most countries today, many buildings are nearing the end of their design lives [1]. With the rapid development of engineering and city, the proportion of buildings is increasing year by year, and the structural complexity and safety of buildings are also highly valued.

Large structures such as Bridges, Dams, tunnels, due to long-term under various loads and building materials such as corrosion, aging, can produce the structure deformation, damage. China's construction industry has developed rapidly. Because the density of buildings exceeds the environmental capacity, some areas become accident-prone areas, and problems such as building settlement and collapse occur frequently [2]. Rapid development of construction industry and transportation industry increase the number of bridges and buildings. Steel has the characteristics of high toughness and strong earthquake resistance. Therefore, steel is one of the main materials in buildings and bridges. When buildings or bridges are used for many years, the internal steel structures begin to be damaged and deformed. So how to detect these problems and reduce or avoid this kind of disaster is very important.

At present, the evaluation of structural integrity is mainly based on the mutual formula of artificial judgment by empirical observation, which is time-consuming and costly [3]. Planned repair and maintenance of the structure can also be difficult. Structural health monitoring (SHM) can greatly reduce the periodic inspection and determine the damage degree of the structure more accurately. At the same time, the residual life of the structure and the reinforcement of the structure can be better evaluated. In order to solve SHM and damage detection in problems and find the adequate methods to monitor the structural health of buildings, this essay analyses and summarizes three methods that are more competitive than the traditional methods, called wireless sensor network subsystem, global navigation satellite system technology, ultrasonic flaw detection technology, and this paper aims to

expounds the principles of the three schemes, analyzes their advantages and disadvantages and future development prospects.

2. Wireless sensor network subsystems

The wireless sensor network is applied to the construction of health monitoring, for remote, real-time online monitoring of building structures, Therefore, SHM is of great significance in civil engineering.

With the development of sensor, Micro Electromechanical System (MEMS) and network, wireless sensor network (WSN) is a new information acquisition and processing technology. Today, wireless sensor networks can be made up of many small units, one square inch in size and less than one watt. They are connected by one or more micro controllers to a variety of sensors and wireless transceivers. Many researchers have predicted that with the aid of the development of semiconductor processors, sensor network unit can be reduced to use a microscope to see the extent of applying communications, microelectronics technology of sensor, the semiconductor logic of low power consumption technology integration on a tiny chip, they like dust spreading to all kinds of physical environment, people can even use the surrounding energy as electricity.

2.1 The Principle of WSN

The architecture of WSN is shown in Figure 1. It consists of three main parts: sensing node, terminal node (Sink) and observation object. Sensor nodes are scattered in the observation area to collect data related to the observed object and send the data after collaborative processing to Sink. Sink can realize the communication between sensor network and task management node through Internet or communication satellite.

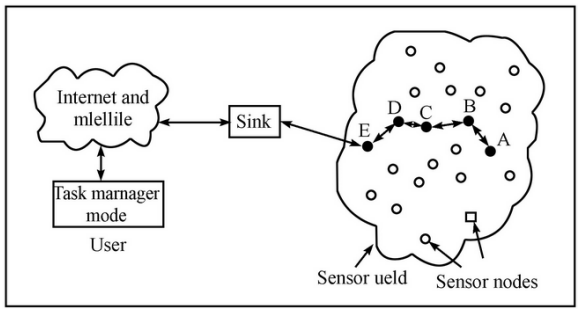


Figure 1. WSN architecture [4]

The data acquisition system needs to select information signals and make decisions according to the transmission frequency of signals, which is closely related to the operating cost of the system. Therefore, relevant designs must be considered scientifically with the help of experiments and detection reagents. Secondly, in order to ensure the authenticity of the collection results, relevant monitoring personnel check and clarify the hardware facilities of the processing project and the acquired signal, minimize the noise in the signal, and convert the information into digital signal. In this process, acquisition nodes need to carry out together, which is generally related to other variable factors in acquisition, resulting in occasional signal distortion and other situations. Therefore, in general practical operation, if the network signal is relatively stable, carry out real-time transmission; If the storage has been completed at the node, it will be processed and transmitted together after the completion of sampling; In another case, the acquisition signal has been processed at the node, and the real-time results can be obtained after the algorithm is added to the node.

In hierarchical network, nodes are mainly divided into three parts, namely sink node, relay node and common sensor node, among which sink, and relay node have very powerful functions. Some foreign researchers designed a two-layer wireless sensor network topology, which is mainly composed of three parts: central site master (CSM), common sensor node, and local site master (L SM) with external power supply. Secondly, the communication of LSM and CSM should be used as the basis for the formation of high-level network. With the help of the underlying network, the sensor

phase can report the collected information quickly to the LSM, while the LSM can quickly transmit the data to the CSM with the help of the high-level network. Researchers in related fields have compiled bridge monitoring systems of different levels according to the actual situation. The sensor node collection device and router form a three-layer topology. In the sensor stage, data is sent by router, and then the router collects data from multiple sensors and sends it to the collection device.

2.2 The characteristic analysis of WSN

The ideal SHM method should be able to accurately detect the damage at the initial stage of the damage, locate and determine the damage degree, and then provide safety assessment of the structure, and predict the residual life of the damaged structure. In this specific field, the application of WSN has the following characteristics:

(1) Health monitoring is to distribute multiple sensors in key parts of the tested object, so once the sensor nodes are arranged, they will not move. In this case, there is no need to consider node mobility. Routing nodes can be manually configured, and data can be sent according to the predetermined path. There is no need for self-organization to form network topology and routing.

(2) Real-time and accurate acquisition of sensing signals and effective analysis of the signal is the key to the whole work. Therefore, the network needs fast real-time response, reliable communication, as far as possible in the shortest time to complete the data collection and preliminary processing, sent to the PC.

(3) In some cases, in order to complete the task of health monitoring, multi-parameter collection is even required in some key parts (different parameters may be collected in each region, such as Lamb wave, optical strain, displacement, pressure, acceleration, temperature, etc., or multiple parameters may be collected by a node). Therefore, the WSN should have the function of selective multi-parameter acquisition.

There are many technical difficulties in the application of wireless sensor system to health monitoring of large structures [5], such as wireless transmission bandwidth, time synchronization of multiple monitoring points, data processing capability of wireless sensor unit of monitoring points, transmission of large amounts of data in wireless public network, post-processing of monitoring data of multiple monitoring points, and post-transmission of lost data packets, etc. Wireless instability and transmission rate bottleneck, the increase of the number of measurement points, the overall performance of the structure after the increase of the number of measurement points, will lead to problems that have never appeared in the wired sensor system, but these problems will not hinder the huge application prospects of WSN.

The application of wireless sensing is very wide, in a variety of large distribution area [6], measurement points, wired connection is difficult or expensive places can play its advantages, such as large pipe network health monitoring, large SHM, protective building monitoring, traffic network monitoring, urban system safety monitoring, battlefield information detection. The application field of WSN is still very broad. In short, the low cost and large range of wireless sensor system will make wireless sensor become the development direction in the future.

3. Global Navigation Satellite System Technology

At present, the global navigation satellite system (GNSS) technology has been initially applied in building safety monitoring. The technology can monitor the objects in real time, to determine the safety status of buildings and reduce the accident probability. In addition, GNSS can effectively reduce the cost of the project. Some specific projects require high accuracy, so experts can use Gaussian algorithm to correct errors, and determine the reliability of uncorrectable errors. There are some differences in every building, the methods of revising them may be different. Therefore, experts suggest that each building can have its own mathematical model, which can ensure the accuracy of the results. But this has greatly increased GNSS technology workload [7].

3.1 The Principle of GNSS

Beidou high-precision positioning technology is one of the typical GNSS technology used in China. Beidou bridge health monitoring system is based on Beidou high-precision positioning technology to monitor the health of the bridges. This system is mainly composed of three parts: GNSS monitoring point, data transmission system, and data analysis and prewarning system. After installing a GNSS receiver at a GNSS monitoring point, the equipment will continue to receive positioning data from Beidou satellite system. After the data is uploaded to the transmission system, it will be converted several times. Finally, the data received from Beidou satellite system will reach the data analysis and prewarning system through the optical fiber line. The data analysis and prewarning system will draw a diagram of the relationship between the horizontal displacement and vertical settlement of the bridge and time based on the data. If the data exceeds the threshold, the prewarning device will give the first, second and third alarm according to the difference.

The principle of Beidou high-precision positioning technology in building monitoring is similar to that of bridge monitoring. As Figure 2 shown, the data processing and service system uses the obtained data to build a three-dimensional model of the monitored building. The three-dimensional model is used to monitor the horizontal displacement and settlement of the building in real time. If the displacement or settlement exceeds a certain range, the system will alarm.

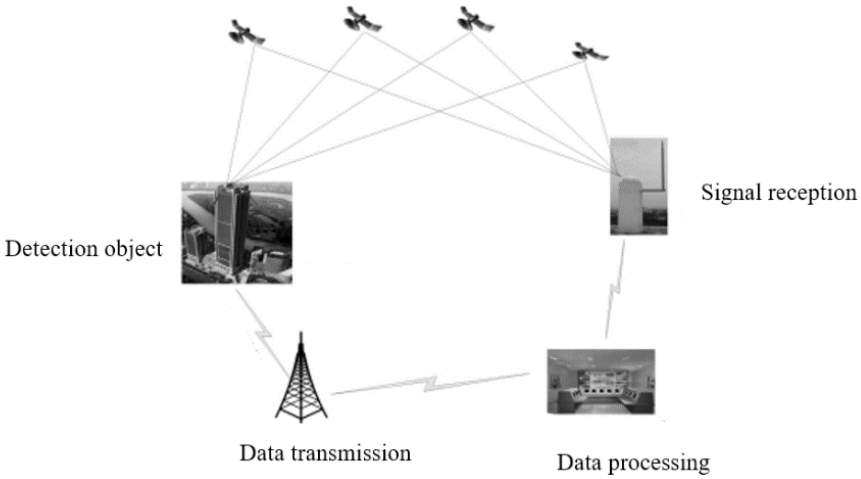


Figure 2. Beidou high precision positioning system [8]

As one of the largest branches of global navigation satellite system technology, Beidou high-precision positioning system is widely used in China. For example, Nanjing No.4 Bridge is the first three-span suspension bridge in China. As an important transportation hub in Nanjing, its health monitoring is completed by Beidou high-precision positioning system. With a total length of 29.996 kilometers, the bridge is equipped with nineteen Beidou monitoring points and two reference points, which are respectively located at the main beam and main cable. After using this monitoring method, relevant departments can know the health of the bridge accurately and carry out timely maintenance [9].

3.2 The characteristic analysis of GNSS

Global navigation satellite system technology has the advantages of high accuracy, being unaffected by terrain, and sufficient room for improvement. For example, because the signals needed in the monitoring process are sent by satellites, obstacles between monitoring points will not affect the normal work of the system [10]. However, the conditions required by GNSS technology is harsh, it needs a satellite as a signal transmitter to maintain the normal operation of the system. For this reason, global navigation satellite system technology cannot be used widely. In order to solve this problem, a high-intensity signal emit source like a signal tower and unaffected by environmental factor should be found to substitute the satellite.

4. Ultrasonic Flaw Detection Technology

Steel is one of the most used materials in steel buildings and bridges because of its high toughness and strong earthquake resistance. When buildings or bridges are used for many years, the internal steel structures begin to be damaged and deformed, so how to detect these problems is very important. At present, ultrasonic flaw detection technology is one of the methods that can detect the damage degree of steel structure without destroying its engineering performance. Besides, corrosion of steel bars in reinforced concrete is also a major factor that endangers the safety of buildings and bridges. The ultrasonic flaw detection technology will focus on how to detect the damage of steel caused by deformation or corrosion [11].

4.1 The of Principle of UFDT

When the steel bars of reinforced concrete begin to corrode, the internal space expands and the concrete protective layer on the surface falls off. The externally applied load will increase, and the remaining steel bars may be unable to bear and collapse. Thus, ultrasonic flaw detection technology is one of the most useful methods to solve this problem. Ultrasonic flaw detection technology mainly uses the reflection of ultrasonic waves inside materials. When ultrasonic waves enter the internal section of steel structure, the ultrasonic waves will be reflected. After the reflected signal is analyzed by the instrument, the size and specific location of the defect inside the structure can be obtained. In order to simulate the corrosion process of reinforced concrete, researchers usually use accelerated corrosion setup to ensure the accuracy of the experiment. Components of the accelerated corrosion setup are shown in Figure 3.

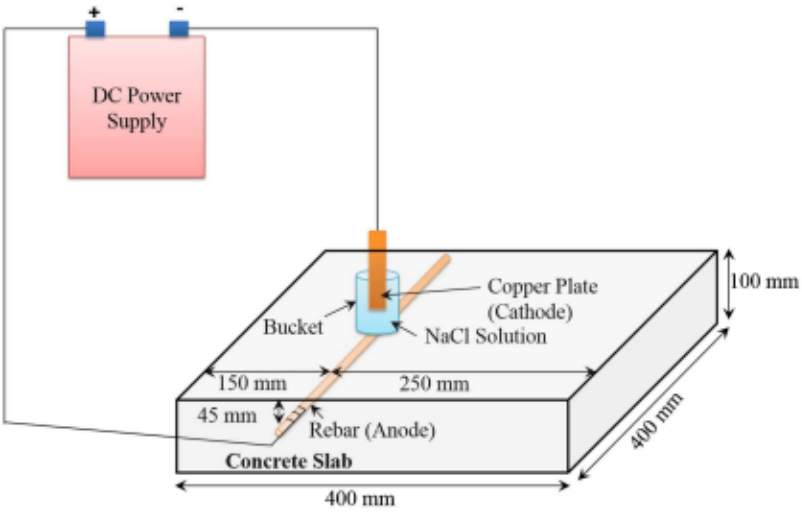


Figure 3. Accelerated corrosion setup [12]

Under normal circumstances, the iron oxide on the surface of steel bars will react with chloride and carbon dioxide, thus failing to protect steel bars, which is one of the reasons for steel bar corrosion. In order to simulate this environment, steel bars were inserted into the concrete sample 45mm deep. And put an open container on the surface of the sample, and then add 3.5% Nacl solution to the container. In order to accelerate the corrosion, the device uses a constant DC power supply. The positive pole of the power supply is connected to the steel bar by wires, and the negative pole is connected to the Nacl solution. Finally, the corrosion was judged by observing whether cracks appeared on the surface of the sample. Some reinforced concrete samples were tested by ultrasonic wave in different time periods, and the data and characteristic values of concrete in different stages were obtained. Generally, it is the initial state (without accelerated corrosion treatment), the eighth day (moderate corrosion) and the eleventh day (the end of corrosion stage). Through the experimental data, we can effectively detect the damage of concrete, thus greatly reducing the cost of maintenance. Ultrasonic flaw detection technology is the most widely used method in the world to detect the safety status of steel.

4.2 The characteristic analysis of UFDT

Ultrasonic flaw detection technology, as the mainstream damage detection method at present, is more convenient and accurate than traditional methods. For instance, the reflection of ultrasonic waves will only be affected by the internal defects of materials but will not be interfered by external factors such as time, light, and temperature. However, ultrasonic flaw detection also has some shortcomings. Different materials have different properties and internal structures. Therefore, the probe of the detector needs to be replaced when testing different materials. This greatly increases the cost of ultrasonic testing. Moreover, this technology is generally applicable to regular testing materials. If the shape of the material is irregular, it may affect its internal structure, resulting in inaccurate results. In order to make up for the shortcomings of ultrasonic flaw detection technology, future researchers can focus on making a universal probe. This kind of probe can detect all types of materials, which can reduce costs and improve efficiency.

5. Conclusions

The research of SHM can reduce the safety problems caused by the building itself, such as the collapse of buildings and bridges, the fatigue of the building structure and the loss of its original performance. Damage detection can accurately find out the damage location and characteristics of buildings, which is conducive to the follow-up maintenance and repair. In this paper, two new building safety detection methods and a damage detection scheme are mentioned. The research method of this paper is mainly to explain the principles of the three schemes, analyze their advantages and disadvantages, make suggestions on the future research direction, and give some examples in daily life. The following conclusions can be made:

(1) GNSS system can ensure the real-time monitoring of buildings, and its accuracy is extremely high. However, due to the lack of popularity of satellite systems, this method cannot be widely used. If there is a signal receiving device that can receive the signal from the signal source and make accurate analysis, then this device can replace the satellite system, which can make GNSS methods widely used.

(2) Wireless sensor network can detect only by arranging the sensors in the detection position. This method is easy to implement, but each sensor can only monitor one kind of data, such as Lamb Wave, Optical Strain, Displacement, Pressure, Acceleration and Temperature. To solve this problem, perhaps future research can focus on developing a sensor that can monitor various attributes, which can greatly improve the efficiency of wireless sensor networks.

(3) Ultrasonic flaw detection technology can effectively detect the damage of steel. However, it takes a long time to use accelerated corrosion device to simulate the corrosion of reinforced concrete, which will greatly reduce the efficiency of detecting the damage of reinforced concrete. Therefore, how to quickly obtain the corrosion conditions of reinforced concrete is an important part of future research.

References

[1] Sun Hongmin, et al. Research progress of structural health monitoring in civil engineering. Journal of Disaster Prevention and Mitigation Engineering , 2003, 23(3): 92-97

[2] Nie Shun. Research on Temperature effect separation and Damage Identification of long-span Cable-stayed Bridge Based on Beidou Monitoring Data . Wuhan University of Technology, 2019.

[3] Shi Jiale, Gao Bo, Dong Ying. Research on Reinforcement Scheme of Existing Building Based on Concrete Reinforcement Corrosion . Building Materials and Decoration,2020, (18):32-33.

[4] Ye Weisong, Yuan Shenfang. Application of Wireless Sensor Network in Structural Health Monitoring . Chinese Journal of Sensor Technology, 2006, (03):890-894.

[5] Maser K, Egri R, Lichtenstein A, et al. Development of a wireless global bridge evaluation and monitoring system , Building an International Community of Structural Engineers. ASCE, 1996.

[6] Shi Xuetao, ZHAO Ming. Wireless Sensor System for Large Structure Health Monitoring . Structural engineer,2005, (04):87-91.

[7] Quesada-Olmo, M.J. Jimenez-Martinez, M. Farjas-Abadia,Real-time high-rise building monitoring system using global navigation satellite system technology , Measurement, 2018, (123): 115-124.

[8] Tang Shuqiang, Si Tingyong, Liang Benren. Design of building deformation monitoring system based on Beidou . Journal of Anhui University (Natural Science Edition), 2017, 41(05): 52-57.

[9] Qi Baolong. Application of Beidou Navigation and Positioning System in Bridge Monitoring . Construction Science and Technology, 2016, (06): 39-41.

[10] Guo Haoyu, Guo Wen. On the application of high-precision positioning technology in building safety monitoring . Jushe, 2018, (16):43.

[11] Hou Jixin, Xiao Zhendong, Wang Xiaonan, Zhang Shunhu. Defect analysis and improvement measures of corrosion-resistant bridge steel plate by ultrasonic testing . Hot Processing Technology, 2015, 44(24):32-234+237.

[12] Debdutta Ghosh, Rahul Kumar, Abhijit Ganguli and Abhijit Mukherjee, Nondestructive Evaluation of Rebar Corrosion-Induced Damage in Concrete through Ultrasonic Imaging , Journal of Materials in Civil Engineering, 2020, (32): 1-13.