Method of Bridge Structure Damage Detection Based on Wireless Monitoring System

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Abstract
Recently wireless sensor networks for structural health monitoring are the hotspots of academic and engineering circles both at home and abroad. The bridge is an important part of the transportation system, and the safe operation of the bridge is related to the safety of life and property of the people and the development of the country's economic construction. Therefore, it is of great theoretical and practical significance to carry on health monitoring for the structural damage to the bridge. This paper proposes a CIRF based on constructive interference for wireless bridge health monitoring system. The flooding protocol adopts RI-MAC mechanism and makes full use of multiple nodes to send data of the length of interference. The simulation results show that CIRF can effectively reduce the flooding delay, reduce the node energy and improve the packet delivery rate. The experimental results show that the damage detection method proposed in this paper is effective, and the design system has great improvement and it is of great significance for research.

Keywords: Wireless Monitoring, Bridge, Flooding Agreement, Damage Detection

1. INTRODUCTION

The emergence of the Internet has changed the way people communicate over distance. The emergence of wireless networks changed the way of the interaction between people and nature, closer to the distance between human and nature, and improve the human’s understanding of the world and the ability to transform the world. The wireless network has been seen as a technology that will have a significant impact on people's lifestyles. Massachusetts Institute of Technology (MIT) technical thinks that the wireless network technology is one of the world's top ten high-tech industry. And in the United States, "Technical Review" gives the next ten emerging technologies, the wireless network among the best.

Bridge structure is a huge investment, it is a large-scale basic transport facility, the popularization of bridge structure promotes the development of the national economy. In recent years, with the continuous improvement of China’s economic strength and the rapid upgrading of scientific and technological level, these also promote the rapid development of bridge construction technology, and bridge modeling becomes more and more gentle and beautiful, large span bridges, especially the cross-sea bridge increased year by year. Bridge’s construction also tends to be much bigger, softer. As a result, more and more attention has been paid to bridge aesthetics and environmental protection, which represents the development of China's bridge construction direction. Once the bridge has structural damage, it must be quickly organized maintenance personnel to carry out maintenance or repair, or will not only make the safety of traffic affected, but also the bridge's service life will be significantly reduced, what's worse, when the bridge suddenly damaged or crashed, it will result in tragic traffic casualties. The typical collapse accident of bridge is shown in Figure 1. This series of tragic accidents not only caused a lot of casualties and significant economic losses, but also had a very bad impact on the community. Therefore, how to use scientific detection methods and assessment methods to ensure the bridge in a healthy condition and durability is very urgent.

2. RESEARCH ON WIRELESS MONITORING SYSTEM

2.1. The Concept and Characteristics of Wireless Monitoring System
The wireless sensor network is a multi-hop self-organizing network system composed of a large number of low-cost micro-sensor nodes deployed in the monitoring area. The purpose is to collaboratively perceive, and collect and process the perceived information of the objects in the network coverage area, and sent to the observer. It can be seen that the three basic elements of the wireless sensor network are sensor nodes, sensing objects and observers.

As is shown in Figure 2, a typical wireless sensor network consists of a sensor node, a sink node, and a management node. Many sensor nodes are distributed in the monitoring area by means of rocket launchers, aircraft sowing, artificial placement, etc., and form a communication network by self-organization. Each node detects and process the simple data of their own information, and then send it to the convergence node through the multi-hop communication. The user publishes the task and collects the data through the management node and manages the entire network. And the management node accesses the sink node through wired network or
satellite channel. The sink node is a node with strong communication capability, processing capability, storage capacity and sufficient energy supply in the network. From the functional point of view, the convergence node is a connection bridge between wireless sensor network and external network, which is responsible for issuing monitoring tasks, and sent the collected data to the external network. In general, a sink node can be either a special gateway device that contains a wireless communication interface without a sense of awareness, or a feature-enhanced sensor node.

![Figure 1. Typical collapse accident of the bridge](image)

2.2. Architecture

Similar to the traditional TCP/IP protocol architecture, wireless network protocols include physical layer, data link layer, network layer, transport layer and application layer. The data layer is mainly responsible for the multiplexing of data streams, data frame detection, media access and error control, to ensure reliable point-to-point and reliable network in the network. The data link layer is mainly responsible for the multiplexing of data streams, data frame detection, media access and error control. Point-to-multipoint communication, also to ensure that the data sent from the source node to reach the destination node completely; network layer is mainly responsible for the establishment and maintenance of the topology, routing selection and maintenance. The routing layer is the core of the network layer. The efficiency of the routing algorithm determines the performance of the whole network. The transport layer is mainly responsible for sending the data in the wireless sensor network to the external network. The application layer mainly includes a series of software for task management and monitoring, the software is the user control and management of the entire network tools. The architecture is shown in Figure 3.

![Figure 2. Sensor network diagram](image)
3. STUDY ON ALGORITHM OF DAMAGE SUBSYSTEM OF BRIDGE STRUCTURES

The purpose of installing a health monitoring system on a bridge is to detect the possible damage within the structure in a timely manner, to further assess the health and safety conditions of ground beam and to alert the potential hazards. Therefore, damage identification is the core technology in the bridge health monitoring system.

Presently, the damage identification of the bridge still faces great challenges. Because of the large size, heavy mass, natural frequency and vibration level of the bridge, the dynamic response is often affected by environmental factors and some non-structural components. Some changes may be mistaken for structural damage and affect the accuracy of the assessment results. The Existing structural damage identification methods can be divided into three categories: dynamic fingerprinting, model correction and neural network.

3.1. Dynamic fingerprinting method

Dynamic fingerprinting refers to the analysis of structural dynamics and dynamic characteristics related to the dynamic fingerprint changes to determine the health of the structure. If the structure is damaged, its structural parameters, such as quality, stiffness, damping, etc. will change, and results in the corresponding dynamic fingerprints change. Therefore, changes in dynamic fingerprints can be used as a sign of structural damage to determine structural damage. Commonly used dynamic fingerprints include natural frequencies, modal shapes, frequency response functions, modal assurance criteria, coordinate mode assurance criteria, and so on.

3.2. Model correction method

The model correction method relies on the finite element model. The initial finite element model based on the structural design blueprint has some differences between the static motion and the actual structure. Therefore, it is necessary to modify the initial finite element model according to the static motion of the actual structure, so that modify the finite element model can faithfully reflect the mechanical response of the actual structure. Finally, the damage identification of the structure is realized by comparing the finite element model with the reference model. Generally, the finite element model can be modified according to the dynamic response of the structure, such as frequency, modal mode, modal damping ratio, and so on. The advantage of model correction is that its concept is clear and can be applied to most engineering problems. However, in the use of model correction method in some complex structures, it is easy to appear too many parameters to be modified, and it is difficult to optimize the process of optimization and calculation is too large and so on.

3.3. Neural network method
The basic principle of neural network for damage identification is to select the parameters sensitive to structural damage as input and the damage state of the structure as output. These samples are sent into the neural network for training, and the mapping between the input parameters and the damage state is obtained. In practical application, only the corresponding parameters of the structure to be measured are input into the neural network, and the damage state information can be obtained. At present, the neural network model for structural damage identification is mostly forward neural network, in addition to dual propagation neural network, autoregressive neural network, radial basis function neural network, fuzzy neural network and so on.

4. METHOD OF DAMAGE DETECTION IN WIRELESS MONITORING SYSTEM IN BRIDGE STRUCTURES

4.1. System Overview

A complete structural health monitoring system consists of four parts: a sensing subsystem, a data acquisition subsystem, a data transmission subsystem, and a damage identification subsystem. Each subsystem involves different hardware and software, to complete the different functions of their mutual cooperation, co-operation, together to complete the task of bridge health monitoring. The whole system works by means of a sensor subsystem that uses sensor-aware environmental data and data acquisition subsystem to collect and collate the data. The data transmission subsystem transmits these data to the damage identification subsystem, and the final damage identification subsystem uses the data obtained by structural damage identification method for bridge health assessment, the whole system is shown in Figure 4.

According to the design of the algorithm flow, the specific steps are as follows:

(1) Sensing subsystem.

The sensing subsystem collects data through real-time monitoring of bridges by various types of sensors. Monitoring content is divided into two categories: load and structural response. Among them, the load includes traffic load, wind, temperature, earthquake, etc.; structural response, including strain, acceleration, displacement and so on. The bridge monitoring system nodes are shown in Table 1.

<table>
<thead>
<tr>
<th>Sensor node</th>
<th>processor</th>
<th>chip</th>
<th>Memory</th>
<th>feature</th>
<th>Example system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mica2</td>
<td>ATMega128L</td>
<td>CC1000</td>
<td>512KB</td>
<td>Low energy consumption</td>
<td>Reyer[40]</td>
</tr>
<tr>
<td>MicaZ</td>
<td>ATMega128L</td>
<td>CC2420</td>
<td>512KB</td>
<td>Low energy consumption</td>
<td>KIM[22]</td>
</tr>
<tr>
<td>IMote2</td>
<td>PXA270</td>
<td>CC2420</td>
<td>32KB</td>
<td>USB interface</td>
<td>Jang[21]</td>
</tr>
<tr>
<td>Tmote</td>
<td>PXA270</td>
<td>CC2420</td>
<td>-</td>
<td>USB interface, Low energy consumption</td>
<td>Chebrolu[11]</td>
</tr>
</tbody>
</table>

(2) Data acquisition subsystem

Signal sampling frequency, signal preprocessing W and data storage / transmission strategy are some of the issues to be considered in the data acquisition subsystem. The choice of sampling frequency is a key problem in the data acquisition process. If the sampling frequency is too high, a single node will quickly generate a large amount of sampling data and increase the storage and communication costs, while the system for the synchronization between nodes more demanding; if the sampling frequency is too low, it will lead to the collection of data can’t be true effectively reflect the structural characteristics of the bridge. In the actual system, the signal sampling frequency is usually determined based on the frequency response range of the bridge monitoring content. For example, the static changes of the bridge, such as deformation, tilt, etc. have very low frequency characteristics, the sampling frequency is usually less than 1HZ; and bridge vibration frequency of
20HZ or so, should choose 50HZ above the sampling frequency.

(3) CIRF-based Data Transmission Subsystem

The basic process of CIRF is that when the receiving node wakes up and sends beacon, its neighbor nodes send beacon in the corresponding time slot in the previous frame, and send the packet immediately at the end of the forward. In the flooding process, when a number of sending nodes while waiting for a receiving node will occur when the length of interference. Figure 5 is an example of a CIRF. At the beginning, both S1 and S2 are waiting for R to wake up. At some point, R wakes up and broadcasts beacon. Followed by the first time, S1 and S2, respectively, in its corresponding time slot sent beacon. The front gorge is over, and S1 and S2 send the packet at the same time. R is able to receive this packet with a higher probability due to the simultaneous transmission of the resulting interference. The packet reception rate can be obtained from the following formula.

\[
G = \sum_{i=1}^{k} (A \cos \alpha_i \tau_i)^2
\]  

(1)

\[
P_e = Q \sqrt{2G \frac{S}{N}}
\]  

(2)

\[
P_s = \sum_{i=9}^{32} Q (32, i) (1 - P_e)^{32-i} P_e
\]  

(3)

\[
PRR = (1 - P_e^{1})
\]  

(4)

4.2. Simulation test and result analysis

In the CIRF, when the node has more than five neighbor nodes, M is set to 5, and the five neighbor nodes with the highest packet reception rate are selected to allocate the timeslots in the preceding posts; otherwise, M is the number of neighbor nodes. Therefore, M is defined as follows:

\[
M = \begin{cases} 
\text{num} if (\text{num} \leq 5) \\
5, if (\text{num} > 5)
\end{cases}
\]  

(5)

![Flooding Delay](image-url)
Figure 5. Flooding delay

Figure 6. Energy efficiency
Figure 7. Packet delivery rate

(1) Flood delay: In Figure 5 (a), with the increase in the number of nodes in the network, the flooding delay of each algorithm is also increasing. However, compared with RI-MAC, ADB, opportunity flooding algorithm, CIRF algorithm delay increase trend is relatively slow. Moreover, the flooding delay of CIRF is always smaller than that of several other algorithms. In Figure 5 (b), with the increase of network duty cycle, the flooding delay of each algorithm is declining. However, in the case of different duty cycle, CIRF flooding delay is better than several other algorithms.

(2) Energy efficiency: In Figure 6 (a), with the increase in the number of nodes in the network, the network node in the working state of the time is naturally increased. However, at different network densities, the number of energy-consuming time slots in the CIRF is always less than that of several other algorithms. In Figure 6 (b), as the duty cycle increases, the time at which the nodes are active in the network tends to decrease. However, in the case of different duty cycles, the number of energy-consuming time slots in the CIRF is always less than that of several other algorithms.

(3) Packet delivery rate: In Figure 7 (a), with the number of nodes in the network increases, RI-MAC, ADB packet delivery rate showed a downward trend, random flooding algorithm maintained at around 99%, while CIRF is always maintained at 100%. In Figure 7 (b), with the change in duty cycle, the algorithm of the packet delivery rate is higher, but only CIRF always maintain 100% of the packet delivery rate.

5. CONCLUSION

Wireless monitoring integrates sensor technology, modern network technology, wireless communication technology, distributed information processing technology and other technologies, is a hot research field of domestic and foreign academic circles. In this paper, the application of wireless network in bridge structure damage monitoring research, mainly achieved the following two aspects:
The application of wireless monitoring in bridge damage monitoring is discussed. On the basis of introducing the relevant background, the components of the structural health monitoring system are introduced in detail: the sensing subsystem, the data acquisition subsystem, the data transmission subsystem and the damage identification subsystem, and then combined with specific application examples. Out of the key technologies in the system: node deployment technology, energy management technology, time synchronization technology, and finally summed up the existing problems in the existing system and the future research and development trends put forward their own point of view.

(2) Based on the study of the wireless monitoring flooding protocol, a reliable flooding protocol CIRF based on the length of interference is proposed for the wireless bridge health monitoring system. The flooding protocol combines the interdigitated interference with the RI-MAC mechanism used in the data link layer to take advantage of the long-term interference that occurs when multiple nodes send data together to avoid redundant transmission of data and improve the reception of nodes Receive probability. Simulation results show that the algorithm has great application value.

Acknowledgement

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References


