Damage Identification Algorithm of Beam Bridge Structure Based on Curvature Mode and Strain Mode

Hao Wang, Kun Ma*

Department of Science, Kunming University of Science and Technology, Kunming, China

*Corresponding author

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Abstract: As most structural health problems of buildings are cumulative damages, they are difficult to be detected in real time. The complexity of actual structure and environmental noise makes structural health monitoring more difficult. The existing methods require a large amount of data when training models, but the marking of data is very complicated in practice. In order to overcome this problem, a wireless sensor network is equipped, and curvature mode and strain mode are adopted to realize bridge structure health monitoring. Then curvature mode and strain mode algorithm training are carried out on the basis of feature extraction through a large number of unlabeled instances, so as to realize data dimension compression and unlabeled data preprocessing. Secondly, the grid environment Morphin search tree algorithm is used to realize the prediction of bridge structure health monitoring categories. Meanwhile, Hessian optimization is improved based on linear conjugate gradient. The semi-positive definite Gaussian-Newton curvature matrix is used to replace the uncertain Hessian matrix, and secondary target combination is carried out, so as to improve the efficiency of grid environment Morphin search tree algorithm. The experimental results show that the proposed grid environment Morphin search tree bridge structure safety detection algorithm realizes high-precision structural health monitoring at the curvature mode and strain mode levels of environmental noise.

1. Introduction

In the structural health monitoring of bridges, each structural type is accompanied by a tendency to vibration, which is characterized by the vibration amplitude on some frequencies larger than that on other frequencies [1-2]. The impact of physical properties of the structure on the shape of modal is considered as the theoretical basis of the modal identification method. Therefore, changes in the physical properties of any structure will lead to detectable changes in the shape of modal. The bridge detection is mainly designed to identify and judge the vibration of external excitation source caused by wind load and traffic load based on data fusion processing technology of damage identification network of beam bridge structure [3].

2. System model and background

2.1 Background

The system model used in this paper is similar to that shown in Literature [10], but the difference is that semi-local processing is used instead of centralized processing. It is supposed that there is n sensor node (s) in the damage identification network of beam bridge structure, and the data are collected at sampling frequency F_S by the original data packet with L sample (s). In the existing TSE indicators, the sensor acquisition data collected at different times have the same sampling frequency. The schemes of centralized processing and semi-local processing are shown in Figure 1.

For the purpose of calculating the shape of the model, the first step in the FDD method is to determine the cross spectral density (CSD) of the sensor output signal matrix. Generally, CSD matrix can be determined by obtaining an average CSD matrix from several data frames. The second step

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of FDD method is to apply singular value decomposition (SVD) to the average CSD matrix at each discrete frequency. The maximum value of the singular value matrix is collected in a vector, and the natural frequency of the system can be identified from its peak value.

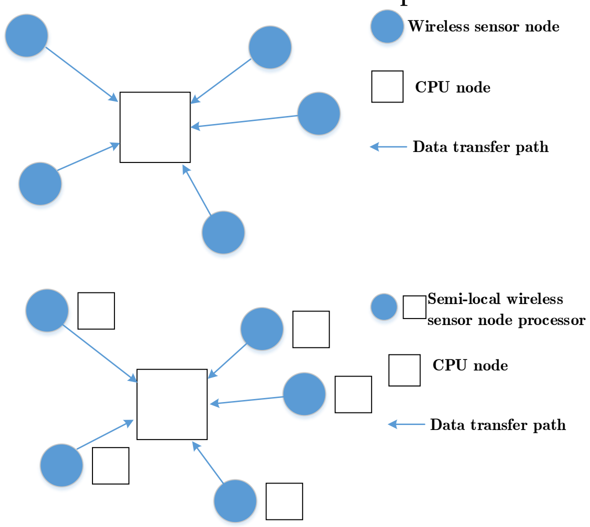

Fig. 1. Scheme of Centralized Processing and Semi-local Processing

2.2 Data acquisition

The structural health monitoring system of bridges designed in this paper consists of three algorithmic levels: (1) layer for data preprocessing; (2) feature extraction layer; (3) modal recognition layer. The specific structure description of the system is shown in Figure 2. In order to verify the effectiveness of the proposed system structure detection algorithm, a three-span bridge is selected as the research object in this paper. The damage identification nodes of beam bridge structure are deployed at the key joints of bridge structure. The acceleration detected by sensors will be transmitted at a specific sampling interval, which is expressed as follows:

$$D_i = \{d_1, d_2, \cdots, d_t, \cdots\} \tag{1}$$

The condition of bridge structure can be monitored by operating the daily collected sample data.

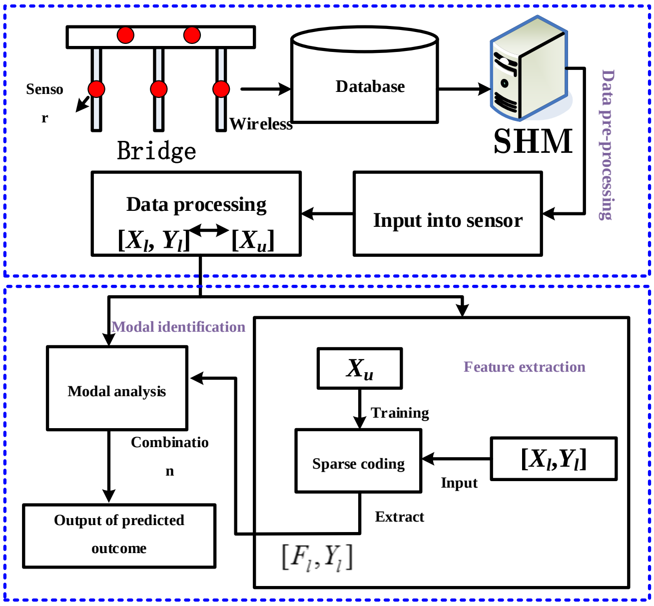

Fig. 2. Bridge Structure Monitoring System

In Figure 2, the expression $[X_l,\ Y_l] \leftarrow [X_u]$ means sample data and labels, and $[F_l, Y_l]$ means signal characteristics indicating bridge structural health condition.

2.3 Data pre-processing

Sample data collected by sensors can be expressed as time series or infinite vectors. During sample pre-processing, samples expressed in time sequence are divided into time frames, as shown in Figure 3. If the number of time frames attached to the bridge is r, the sampling frequency of the sensor R is f and the time frame is t. Serial sample data may be obtained by the following formula:

$$x = \left(p_1, p_2, \cdots, p_r \right) \in R^{r \times t \times f} \tag{2}$$

Given that label is $y \in \{1, 2, \cdots, C\}$ and C is the number of modal categories, the sample set $\{x, y\}$ can be established. Furthermore, the following formula can be obtained:

$$((x_l^{(1)}, y^{(1)}), (x_l^{(2)}, y^{(2)}), \cdots, (x_l^{(m)}, y^{(m)})\} \tag{3}$$

If the bridge is in a healthy state, an example may be unmarked as follows:

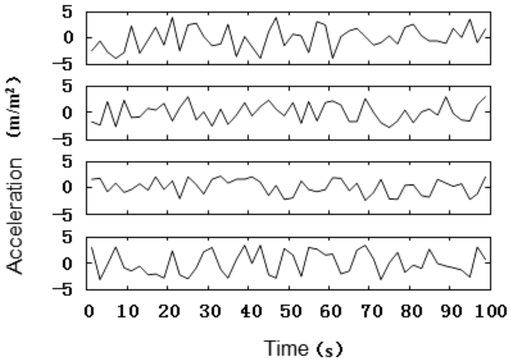

Fig. 3. Sample Pre-processing

The curvature modal and strain modal of the features may be found in the relevant literatures, so that they will not be covered again here.

3. Morphin search tree path planning in grid environment

The design concept of Morphin search tree is mainly based on two aspects: (1) to achieve better obstacle avoidance ability; (2) to achieve real-time correction of path planning. Morphin search tree is designed to update the detected area in real time, obtain more robust feature extraction, and achieve superior path planning and obstacle avoidance ability for the dynamic environment target area.

3.1 Morphin search tree in grid environment

Based on the grid information on the driving route of the logistics transport vehicle, the dynamic window of the driving process is established with the transport vehicle as the central zone: $win\left(p_R(t)\right) = \left\{p \mid p \in C, d(p, p_R(t) \le R_r\right\}$. The window is also known as the visual field in the driving area of logistics transport vehicle. In the window model, parameter R_r is the visual field perception radius of the logistics transport vehicle, parameter $p_R(t)$ is the location of the vehicle routing at the selected time t, and parameter C is the visual field in the driving area of logistics transport vehicle. In this research, the dynamic window method is mainly adopted to plan and design the vehicle routing, which realizes the real-time adjustment in the search process of Morphin search tree combined with the grid information on the global path, depending on the information recognition ability of the on-board identification system, so as to realize the optimal design of the path planning process.

It is assumed that the running speed of the vehicle is v_t and the braking distance of the vehicle is d_e in the path planning model of the logistics transport vehicle. The acceleration and maximum braking speed during braking process are a_{break} and v_0, respectively. The following formula can be used to calculate the above values:

$$\begin{cases} 2 \cdot a_{break} d_e = v_t^2 - v_0^2 \\ d_e = (v_t^2 - v_0^2) / (2 \cdot a_{break}) \\ d_e = v^2 / (2 \cdot a_{break}) \end{cases} \tag{4}$$

Given that the arc length of the Morphin search tree generated in the process of path planning for logistic transport vehicles is L_{arc}, which should be greater than parameter d_e from the perspective of predicting the situation ahead. If the vehicle or obstacle ahead is located in the arc of the search tree, an early warning signal will be sent. The deflection of search angle parameters of Morphin search tree and the search path of Morphin algorithm have relatively consistent corresponding attributes, and the path planning results obtained by Morphin search tree have relatively local optimal characteristics. Figure 4 shows a schematic evaluation result based on Morphin search tree.

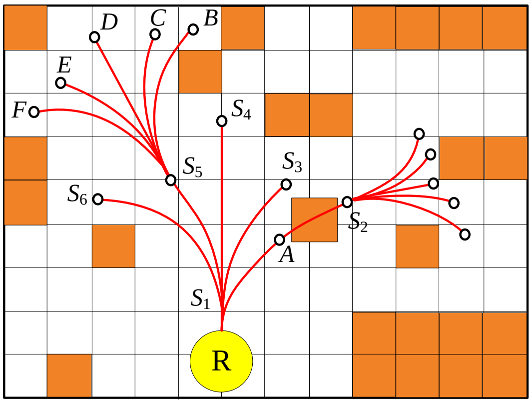

Fig. 4. Evaluation Diagram

In the evaluation diagram shown in Figure 3, the search path of Morphin algorithm is optimized during the signal lamp cycle. At the same time, the braking process is restricted from the angle of safe driving, and imposed with the following constraints:

(1) The set path length of searching arc L_{arc} in Morphin algorithm should be shorter than the braking distance d_e.

(2) The result of set path length of searching arc L_{arc} in Morphin algorithm multiplied by the multiplicity parameter m of the search tree algorithm should be less than the visual field radius of the logistic transport vehicle. The multiplicity parameter m selected in this study is 3.

3.2 Path evaluation strategy

The grid evaluation model is established for 2D environment of running path of logistics transport vehicle. The arc is mapped to the nearest grid model by the nearest mapping method. The degree of freedom, safety index and unblocked index of the mapping arc are also evaluated. Firstly, the grid model coordinate system of running path of the logistic transport vehicle is constructed, and the included angle α between the logistic transport vehicle and the target location is calculated by following formula:

$$\alpha = \arccos \frac{x_g - x_r}{\sqrt{(x_g - x_r)^2 + (y_g - y_r)^2}} \tag{5}$$

Where, the coordinate term (x_g, y_g) is the dynamic coordinate of the logistics transport vehicle and (x_r, y_r) is the dynamic coordinate of the radar detector. Firstly, the coordinates of the research object in α coordinate system should be converted to obtain the polar coordinate θ with the radar detector as the origin. In case of $d_\theta \le L_{arc}$ with respect to the distance between the target and the polar coordinate θ, the above interval is called peak-fan interval; in case of $d_\theta > L_{arc}$, the above interval is called valley-fan interval. On this basis, the passing rate index of logistics transport vehicles can be defined as follow: in case of $L_{arc} \le d_e$, the passing rate index is $T_r = 0$; in case of $d_e < L_{arc} < d_\theta$, the passing rate index is $T_r = L(S_1A)/L(S_1S_i) \in (0,1]$. In the above index calculation model, $L(S_1A)$ means length of arc S_1A, $L(S_1S_i)$ means length of arc S_1S_i.

If the logistics transport vehicle is close to the vehicle or obstacle ahead, it is necessary to set a safety threshold as d_{S_0} and the shortest distance between the logistics transport vehicle and the vehicle or obstacle ahead as d_n in order to avoid collision. If $T_s = d_n/d_{3_n}$, then $d_n < d_{S_0}$. Otherwise, angle θ_i of detection arc of logistics transport vehicle in polar coordinate system is calculated given that $T_s = 1$, so that the steering calculation formula of logistics transport vehicle $T_g = |\theta_i - \theta_j|$ is obtained. The safety evaluation index can be defined as:

$$E_s = \alpha_1 T_r + \alpha_2 T_s + \alpha_3 T_g \tag{6}$$

Where, parameters α_1, α_2 and α_3 are weight parameters of the safety evaluation index, which can be determined based on the grid environment information on the running path of the logistics transport vehicle.

4. Conclusion

To monitor the health condition of bridge structure, a semi-local TSE robust detection method of bridge structure health based on damage flexibility method is constructed by equipping the damage identification network of bridge structure. In order to reduce the data transmission from sensor nodes to the central unit, a semi-local processing method is used to process the data of each sensor node locally. The detected vibration signals are processed by Fast Fourier Transform (FFT). The obtained FFT values are transmitted to the central unit or cluster head for further processing. Finally, the damage signals are detected and located by flexibility method, so as to realize better damage detection effect.

Acknowledgement

The damage identification research of preset damaged reinforced concrete beam based on the modal parameters.

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