Design and Application of Bridge Operation Monitoring Scheme

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Abstract. The frequency and depth of routine inspection of the operation status information of the completed bridge are far from the requirements of grasping the health status of the bridge, so it is necessary to design and establish a modern, automatic and intelligent operation monitoring system. Taking Nanjing Yangtze River Bridge as an example, this paper designs a bridge operation monitoring system based on Web, from the system design ideas to the development of monitoring content, the final design of the system, including the overall system function architecture design, subsystem design and so on. Focus on the sensor monitoring of a variety of characteristic value data analysis and processing, proposed based on BP neural network to establish a feature layer data fusion model of the solution, to achieve long-term, timely and systematic monitoring of bridge structural status and traffic conditions, serious anomalies can be issued to the relevant units and bridge management and maintenance units warning. To provide targeted reference and guidance for bridge maintenance and maintenance decisions.

Keywords: Operation period monitoring, Bridge structure, Data processing, System design.

1 Introduction

Since the 21st century, China has paid more attention to the maintenance, maintenance, reinforcement, condition assessment, health monitoring and other aspects of Bridges after construction and operation. Ensuring safe operation of Bridges after construction and avoiding catastrophic accidents has become the top priority of attention of bridge management department [1]. On May 3, 2021, a section of light rail viaduct collapsed in the suburb of Olivos, Mexico City, the capital of Mexico City, resulting in the derailing of a metro train, which caused at least 25 deaths and more than 70 injuries. The Office of The State Council Safety Committee issued an emergency notice on "Deployment to strengthen urban rail transit safety work". It requires further strengthening the operation testing, monitoring, maintenance and maintenance management of key equipment and facilities [2]. According to the Ministry of Transport's Statistical Bulletin on the

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Development of the Transportation Industry in 2021, by the end of 2021, there will be 961,100 highway Bridges with 73.8021 million extension meters nationwide. After decades of rapid development, China's bridge health monitoring system has made great progress in engineering application [3]. In 2007, the structural health monitoring system was designed and installed on Lishui West Bridge, the first subway cable-stayed bridge in Asia of Beijing Metro Line 5. In 2011, a viaduct of Guangzhou Metro Line 4 carried out real-time monitoring of bridge alignment and structural vibration [4]. In 2017, a deformation monitoring system was installed on a light rail viaduct spanning an expressway in Tianjin to realize real-time, remote and high-precision monitoring [5]. Although there are still many related cases, there are still many problems. First, the synchronization of monitoring data is poor, and even anomalies such as packet loss, drift, and cycle jump appear. Second, the domestic monitoring system only focuses on sensor data acquisition, while the system data analysis and algorithm processing are not deeply studied. In this paper, Nanjing Yangtze River Bridge as the engineering background, according to the survey found that the system for many years lack of maintenance management, has basically lost function, in a state of paralysis, reduce the service level of the bridge structure, respectively from the system design ideas, monitoring content and system data analysis and algorithm processing and other aspects, proposed a web-based bridge operation monitoring system scheme.

2 Project overview

Nanjing Yangtze River Bridge Railway bridge is a key project across the Yangtze River on the Beijing-Shanghai railway trunk line, while the road bridge is not only an important river crossing channel in East China, but also a transportation hub on both sides of the Yangtze River in Nanjing. Since its completion in 1968, the bridge has made outstanding contributions to the national, regional and local economic development. The highway bridge is composed of four parts: the North bank approach bridge, the main bridge, the South bank approach Bridge and the Huilong Bridge [6], as shown in Figure 1. The highway bridge is 1576m in length, located between the two bridgeheads, with a total of 10 spans. From north to south, it consists of 1 hole 128m simply supported steel girder and 3 pairs of 160m third-span continuous steel girder [7]. The bridge deck adopts the overall structure of orthotrophical steel bridge panel, which is composed of longitudinal ribs (beams), beams and stiffened steel bridge panels [8]. Highway approach bridge T beam bridge are simply supported structure, each hole beam end is equipped with expansion joints and expansion devices, the upper structure is prestressed concrete structure, because of the structural characteristics of the bridge head building, cross section and bridge deck layout forms are diverse, the pier is a double-column frame structure. Highway approach bridge double-curvature arch bridge is connected to the T beam bridge inside, the outside is connected to the approach road, a total of 22 holes, including 4 holes on the north bank, 18 holes on the south bank, each hole is equal section catenary hingeless arch, the span ratio of 1/4 ~ 1/5, the south and north bank approach bridge span 27.68m ~ 34.9m, double-curvature arch bridge deck is not equipped with expansion joints and expansion devices. The main arch circle is composed of 16 arch ribs and 15 arch waves, and the height of the main arch circle is 78.5cm [9]. Huilong Bridge starts from the intersection of T-beam bridge and double-curvature arch bridge on the South bank approach Bridge, and is connected with the newly built ramp bridge. At present, there is basically no social vehicle traffic.

Fig. 1. General picture of Nanjing Yangtze River Bridge

3 Operation monitoring scheme design

3.1 Design ideas

Combined with the results of preliminary structural testing, the bridge operation monitoring system adopts the monitoring methods of automatic structure monitoring and monitoring management of overweight vehicles. Sensors are installed at key parts of the bridge structure to monitor the key positions that affect structural safety and traffic safety and the weak positions of the structure, identify various abnormal information of the bridge structure and give timely alarm to ensure the safe operation of the bridge structure. And extend the service life of the bridge through timely and reasonable maintenance, and provide decision-making basis for the operation and maintenance of the bridge.

The system should have the following basic functions, in order to achieve this function of the system design general idea is shown in Figure 2.

(1) Real-time monitoring and acquisition of bridge load source and structural status information;

(2) To provide reliable safety state assessment for the reasonable management and maintenance of the bridge;

(3) reduce manual testing workload and improve monitoring, testing and office efficiency;

(4) to realize the automation, information and intelligence of bridge operation monitoring;

(5) Monitor the information of passing vehicles, and timely release the information of overweight vehicles;

(6) Establish the time dimension and space dimension structure database of the bridge, and analyze the state evolution of the bridge structure;

(7) Realize the integrated management of bridge maintenance and improve the digitalization, systematization and information of maintenance management.

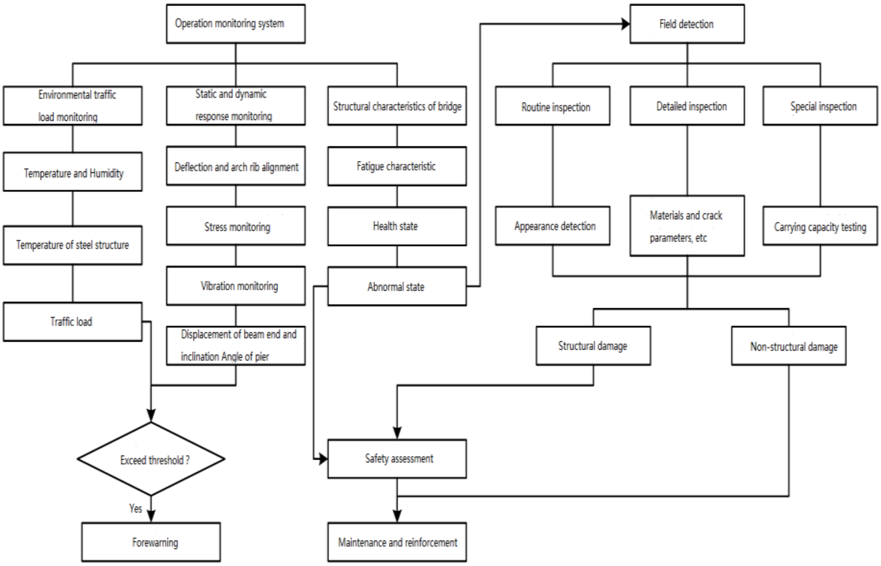

Fig. 2. Schematic diagram of the general idea of operation monitoring scheme design

3.2 Monitoring Content

According to the structural status and design ideas of Nanjing Yangtze River Bridge, the specific monitoring content of the system should include the following parts:

(1) Highway bridge structure monitoring content: environmental temperature and humidity monitoring, beam end displacement (bridge panel and steel truss beam) monitoring, steel structure fatigue stress monitoring, bridge panel structure vibration monitoring;

(2) Railway bridge structure monitoring content: support displacement monitoring, vibration amplitude monitoring, railway surface video monitoring;

(3) highway approach bridge T-beam structure monitoring content: support displacement monitoring, pier tilt monitoring;

(4) highway approach bridge hyperbolic arch structure monitoring content: arch vertical displacement monitoring, pier top bridge panel displacement monitoring, concrete corrosion monitoring, arch rib stress monitoring;

(5) Highway bridge pavement monitoring content: asphalt concrete stress monitoring, steel structure stress monitoring;

(6) Highway traffic monitoring content: vehicle weighing monitoring, license plate recognition monitoring, highway surface video monitoring.

3.3 System design

3.3.1 System function architecture.

In order to realize the expected functions of the system during the operation of the bridge, its overall architecture is designed as shown in Figure 3.

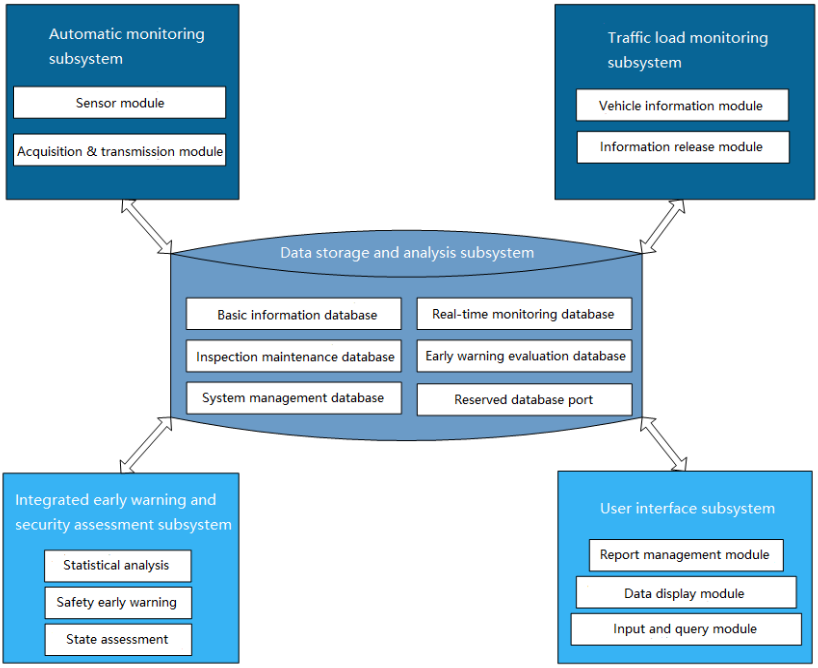

Fig. 3. The overall structure of the system

The bridge operation monitoring system is composed of the above five subsystems, among which the automatic monitoring subsystem and traffic load monitoring subsystem are used to collect information such as environment and vehicle load and structural response data, and the acquired data are filtered and uniformly stored in the data storage and analysis subsystem, and statistical analysis is carried out through corresponding algorithms. Combined with the safety threshold set by each characteristic parameter, the system can realize the comprehensive warning and status assessment functions, and the user interface subsystem can complete the human-computer interaction work (including real-time data graph display function, manual information input and input, etc.).

3.3.2 Automatic monitoring subsystem.

The subsystem combines the structure and operation characteristics of the bridge, reasonably chooses and arranges the monitoring content and monitoring points, automatically obtains the structure status and vehicle parameter data through certain collection and transmission strategies, uses the data processing and control equipment to further process the collected data, and provides analysis data for the safety alarm and status assessment subsystem. And it is selectively and hierarchically stored in the data storage and analysis subsystem [10]. The design of the subsystem is mainly composed of sensor module, data acquisition and transmission module. The hardware basis of the entire operation monitoring system of the sensor module is mainly composed of various sensors and special equipment arranged on the bridge structure. Part of the design is shown in Figure 4. By analog signal or digital signal feedback to the data acquisition and transmission module. Data acquisition and transmission module can be designed as data acquisition sub-module, data transmission sub-module and auxiliary support sub-module three parts, one data acquisition sub-module is arranged in the bridge structure or bridge floor conditioning equipment, acquisition equipment, acquisition computer and sensor cable network, etc. The second data transmission sub-module is composed of network transmission equipment and network transmission cables arranged in the bridge's external field workstation cabinet and the monitoring room's computer room, and the third auxiliary support sub-module is composed of the normal operation of the external field and the monitoring room's equipment, including the external field cabinet, external field chassis, power distribution and UPS, lightning protection and remote power monitoring and other equipment [11].

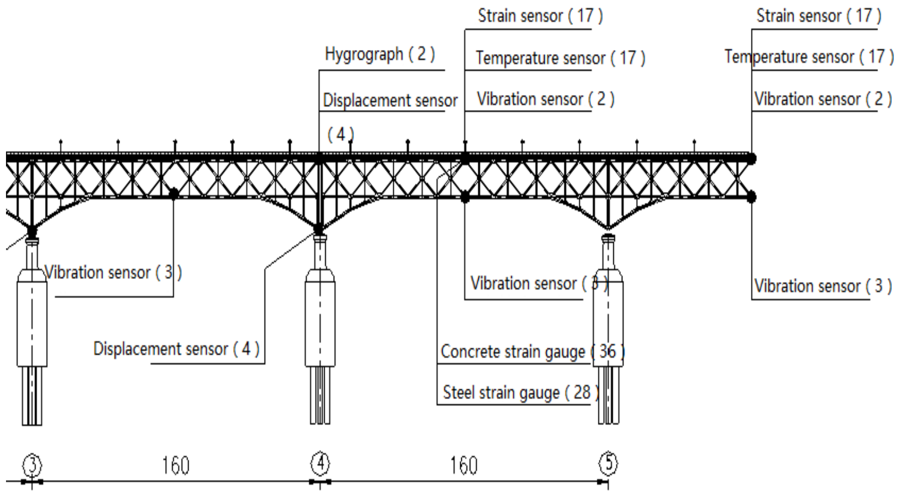

Fig. 4. A part of the sensor module layout diagram

3.3.3 Traffic load monitoring subsystem.

The traffic monitoring subsystem is composed of vehicle information monitoring module (overweight vehicles and traffic flow) and video monitoring module. The vehicle information monitoring module includes dynamic weighing and license plate recognition, and monitors the total vehicle weight, axle weight, axle number, speed and license plate of each vehicle. In the later stage, the monitoring data can be analyzed and counted, and the traffic volume can be counted and predicted. The video monitoring module is mainly for monitoring the driving condition of vehicles on the bridge.

3.3.4 Data storage and analysis subsystem.

The design of the system is mainly to complete the monitoring data verification, structured storage, management, visualization and monitoring sampling control and other work. The contents include: collecting, processing, analyzing, displaying, archiving and storing all the signals, sending the processed and analyzed data to the integrated early warning and safety assessment subsystem to evaluate the structural safety status and produce monitoring/evaluation reports.

(1) Data processing

The data processing in the operation monitoring system is the deep-level mining of the signal after the signal is obtained, which is the process of obtaining effective knowledge from massive information. Since the bridge receives a variety of different loads, temperature loads, vehicle loads and material degradation have different impacts on the different acquisition amounts in the monitoring system, so multi-sensor data processing has become the top priority of the system design, because the multi-sensor observation is not the same physical quantity, it is no longer data-level fusion. Therefore, the currently well-developed feature layer fusion technology is adopted to establish the feature layer data fusion model based on BP neural network [12], as shown in Figure 5.

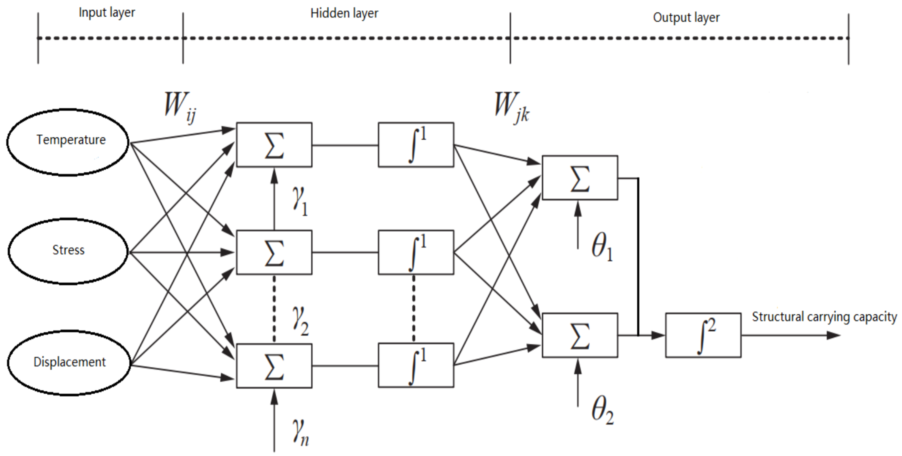

Fig. 5. Feature layer BP neural network data fusion model

The data fusion model first extracts representative features from monitoring data such as environmental temperature and humidity, structural stress, structural deformation, support displacement, pier tilt and traffic conditions, and then fuses these feature parameters of different sizes, ranges and dimensions into a single feature vector (such as structural bearing capacity). The normalization process is shown in equation (1). Finally, the characteristic parameters are identified for decision making.

$$A_i = \begin{cases} 1 & , \ x_i \geq V_{max}^i \\ \frac{x_i - KV_{base}^i}{V_{max}^i - V_{base}^i}, & x_i \leq V_{max}^i \end{cases} \tag{1}$$

A_i—the value of the parameter after normalization treatment.

V_{max}^i—the limiting value of the parameter determined according to the experimental data.

(2) Data management

Data management is to formulate appropriate data acquisition, transmission and storage strategies under the framework of global data management, complete the reading of data from the corresponding sensors through protocol interaction with the corresponding hardware devices and issue collection tasks, and then carry out complex calculation, conversion and statistical analysis of these data to obtain data that can reflect the detection items [13]. The bridge status data is obtained through the data management system as the basis for health assessment, supporting static and dynamic data acquisition, acquisition process control, remote status report and remote control modules.

(3) Data storage and backup

The structured and unstructured data of each collection station are homogenized into a unified database through an independent application program, and then all data is centralized into the central database for centralized storage through a communication agent. In order to speed up the storage and query management of massive data, and break through the limitation of system file size, the storage of massive data adopts data grouping and sub-table technology, makes full use of the advantages of multi-core processing of the server, and greatly improves the storage and query rate. In view of the precious mass data and hardware configuration generated in the system, in order to maximize data security, prevent data loss in special circumstances, and can recover the database system in the shortest time after the system encounters a failure, to maintain the smooth running of the database system, the secondary data backup strategy is adopted. Take the full backup and differential backup on the database server as the first-level backup, and the compressed backup on the remote data backup server as the second -level backup, and burn the second-level backup data to a CD for archiving, and then empty the second-level storage space to ensure the continuous availability of the hard disk storage space, to realize the double-layer protection of all data.

3.3.5 Integrated early warning and security evaluation subsystem.

By monitoring the operation status of the structure, the sub -system evaluates the bearing capacity of the whole bridge and key components through load input, structural response data and regular test data of the bridge, and judges whether the structure is in the normal limit state of use, whether it is about to reach or exceed the limit state of service. The expected functions of the system include: monitoring and reporting the environment of the bridge, traffic loads and parameters, monitoring and reporting the structural response of the main components of the bridge under various loads, and realizing the alarm under abnormal conditions (traffic loads and various types of response exceed the limit). The early warning threshold of the bridge operation monitoring system is divided into two stages. The first stage is the initial stage of the system construction, the system lacks measured data, and the early warning threshold is mainly set according to the multi-level theoretical analysis and calculation results. The second stage is to correct the early warning threshold through the measured data after the operation of the system, and give a more reasonable threshold after the analysis and statistics of the measured data for about 3 years.

The subsystem is an important functional component of the whole monitoring system. Its composition and technical characteristics are as follows:

(1) The subsystem consists of a 64-bit dual CPU structure security assessment server and early warning, evaluation software system.

(2) The subsystem responds to the user's request by WEB, accesses the dynamic database and the historical database.

(3) The subsystem manages the original database and the structure information database, evaluates the structure security status, and generates the structure security status report to the user.

3.3.6 User interface subsystem.

The subsystem is the interaction platform between the user and the operation monitoring system. Through the user interface subsystem, all kinds of data can be displayed to the user in real time according to the demand, and the user can control and input the system. It mainly includes two parts based on online monitoring and evaluation software and bridge data query software.

Online monitoring and evaluation software as the main body, relying on the browser/server system architecture of the online human-computer interaction platform. The system mainly includes real-time monitoring subsystem, threshold alarm subsystem, dynamic weighing analysis subsystem, instant information, video monitoring subsystem, security assessment subsystem, trend analysis subsystem, report reporting subsystem, user management subsystem and other ten functional modules. The B/S architecture adopted by the software is a two-layer C/S architecture on the Web of an application, it simplifies the client, no need to install different client applications on different clients like C/S architecture, and only need to install general browser software. This can not only save the hard disk space and memory of the client, but also make the installation process easier and the network structure more flexible [14].

The data query software mainly includes two functions, the first is the real-time display of monitoring data, which is transmitted to the information control room by wired or wireless means through different sensors, such as vibration sensors, deflection sensors, and then read into the server database process. The system according to the number of different measuring points and the number in the database correspond one by one, to achieve the real-time display of monitoring information of different measuring points. The second is the analysis of real-time monitoring alarm, when the measurement point data exceeds the predetermined threshold, according to the previous summary of the law or the possibility of observation of the precursor, the sensor data can be displayed according to the threshold value.

4 Conclusion

In this paper, a Web-based bridge operation monitoring system is designed according to the structural characteristics of Nanjing Yangtze River Bridge, the results of structural testing in the early stage, maintenance and reinforcement in the later stage and the progress of construction. The overall design idea of the system is oriented by the overall functional requirements of the system, and the modular design is adopted, which effectively improves the system development efficiency and the scalability of the system. Specific from the development of monitoring content to system design, including the overall system function architecture design, each subsystem, module design. Focus on the sensor monitoring data (environmental temperature and humidity, structural stress, structural deformation, bearing displacement, pier tilt and traffic) analysis and processing methods, proposed based on BP neural network to establish a feature layer data fusion model of the solution, to achieve multi-feature value data processing function and put forward data management, storage, query and other subsystems construction scheme. It provides some ideas for the data information design. The bridge operation monitoring system has realized the needs of real-time monitoring, visual display, multi-eigenvalue data processing and analysis of the bridge, which needs further experimental verification, and more modules can be developed to meet the needs of more functions, so as to make contributions to ensuring the safe and normal operation of the bridge, rationally allocating the maintenance resources and reducing the comprehensive maintenance cost of the bridge.

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