Research on Fault Monitoring Device of Highway Bridge Expansion Joint Based on Internet of Things Technology

Youjun Xu(✉)

College of Rail Transit, Nanjing Vocational Institute of Transport Technology, Nanjing 211188, China
xuyoujun569@yeah.net

Abstract. Among various large-scale engineering structures, highway bridge structures are characterized by a large number, long service period, and huge investment. Therefore, any construction quality, safety accidents, natural disasters or structural aging, insufficient bearing capacity, etc. may cause the bridge as a whole or Natural cumulative damage and accidental damage occurred in expansion joints of highway bridges, which affected the safety of bridge operation. Therefore, a research on a fault monitoring device for highway bridge expansion joints based on the Internet of Things technology is proposed. Design the fault signal acquisition equipment of the Internet of Things technology, first analyze the basic characteristics of the road bridge expansion joint fault, design a signal collector based on the Internet of Things technology, and design a signal extractor based on the Internet of Things technology. Design a data acquisition card for the failure monitoring of highway bridge expansion joints. Finally, through example analysis, it is proved that the detection accuracy of the highway bridge expansion joint failure monitoring device combined with the Internet of Things technology is very high, and the fault monitoring accuracy is good, which meets the basic requirements of highway bridge expansion joint failure monitoring.

Keywords: Internet of Things technology · Highway bridges · Expansion joints · Fault monitoring

1 Introduction

The Internet of Things refers to a variety of terminal equipment and facilities, in the private network or Internet environment, through wireless or wired means to achieve interconnection and intercommunication, adopt appropriate information security guarantee mechanisms, and provide personalized real-time remote control, remote maintenance and other management and Service function [1], to realize the integration of equipment management and control. The ZigBee technology is listed as one of the ten new technologies with the fastest development and the broadest market prospects in the world today, and one of the most critical technologies for Internet of Things applications." It is

S.-H. Wang and Y.-D. Zhang (Eds.): ICMTEL 2022, LNICST 446, pp. 17–27, 2022.
https://doi.org/10.1007/978-3-031-18123-8_2

a short-distance, low-complexity, low-power, Low data rate, low-cost two-way wireless communication technology [2]. Its Z-Stack protocol stack has a clear hierarchical structure, mainly composed of physical layer (PHY), medium access control layer (MAC), network layer (NWK) and Application layer (APL) composition. In the ZigBee network, users can easily define the role of each unit by compiling the above protocol.

In the process of applying the Internet of Things technology to the fault monitoring of highway bridge expansion joints, the development of the Internet of Things technology in the monitoring of road bridge expansion joint faults has been greatly restricted due to the difficulty of mining the operating data of the highway bridge. The reason why the operation data of road bridge is difficult to mine, the difficulty lies not in the technical level [3], but in the closed nature of the construction industry. In fact, judging from the current technical level, it is enough to realize the mining of highway and bridge data, but it is difficult to obtain the relevant data information, which causes many tasks to be carried out smoothly. At present, my country has gradually begun to be applied to highway bridge monitoring platforms, but because highway bridge developers have not disclosed the core operating data of road bridge, the failure warning function of expansion joints is still difficult to achieve smoothly. Therefore, the Internet of Things companies must work closely with highway bridge manufacturers to fully utilize the advantages of both parties, so that this problem can be effectively solved [4].

The failure of expansion joints of highway bridges brings great difficulties to the maintenance of highway bridges, and also brings many inconveniences to people's production and life. The monitoring device designed in this paper uses wireless sensing technology to realize precise positioning and intelligent monitoring of each node. The staff can easily understand the working status of highway bridges only through mobile phones, computers and other network terminals, reducing the investment of manpower and material resources., Which makes the fault monitoring more humane [5].

2 Design Fault Signal Acquisition Equipment for IoT Technology

2.1 Analyze the Basic Characteristics of the Failure of Highway Bridge Expansion Joints

Expansion joints of highway bridges are one of the important components of bridges. They are generally installed at the junction of the beam end and the road surface at the bridge abutment, between the two beam ends of the bridge beam body, and various expansion devices or joints at the junction of the bridge. The general term of structure, its main purpose is to meet the needs of bridge structure deformation and enable vehicles to pass the bridge comfortably and safely. The expansion joints of bridges are one of the most easily damaged components of the bridge structure [6]. Like the bridge deck system, they all bear the direct action of vehicle load and are exposed to the natural environment for a long time, so it is easy to cause The load-bearing system and anchoring system of the expansion joints are fatigued and damaged, and the repair and maintenance of the damaged expansion joints are difficult due to various reasons. The fatigue damage of expansion joints is the fall of the welded joints of embedded steel bars and anchoring steel bars, the fatigue cracking of concrete in the anchoring area, and the fatigue damage of the system including various forms of expansion joint devices. As shown in Fig. 1:

Fig. 1. Schematic diagram of highway bridge expansion joints

As the bridge continues to be used and the damage to the expansion joint device cannot be maintained and repaired in time, the damage to the expansion joint device continues to accumulate, which further increases the direct role of the vehicle in driving. Such a vicious circle not only accelerates The aging and damage of the expansion joint device will also directly affect the operational safety of the bridge structure.

A large number of studies have shown that long-span bridge structures are huge and easily affected by factors such as the natural environment and operating environment. Under the influence of environmental factors, such as wind load, temperature load, and vehicle load, etc. [7]. For a long-span bridge structure under normal conditions, the characteristic parameters of the bridge structure will float in a wide range. It is precisely because of this fluctuation that the bridge structure is affected by real local damage. The characteristic parameters and signals of the damage caused by the bridge structure are masked or submerged in such fluctuations. Therefore, based on the long-term health monitoring data of the bridge, an objective physical model is established to describe the relationship between the environmental conditions of the bridge and the structural damage characteristic parameters, and on this basis, the monitoring and damage of the overall state of the structure is established for "normalized environmental conditions" Early warning method, this is one of the main research issues of long-span bridge structural health monitoring technology for practical engineering applications.

2.2 Design a Signal Collector Based on the Internet of Things Technology

Aiming at the poor monitoring effect of abnormal signals of the original wireless robot communication fault monitoring device, the design of this communication fault monitoring device was launched. In this research, ZigBee technology is used to optimize the design principle of the original wireless robot communication fault monitoring device [8]. This technology has the characteristics of low power consumption, low cost, high safety and high capacity. Using this technology can effectively improve the poor signal monitoring effect of the original equipment. In order to ensure the effectiveness of this equipment design, the design framework of the communication fault monitoring device is set as shown in Fig. 2:

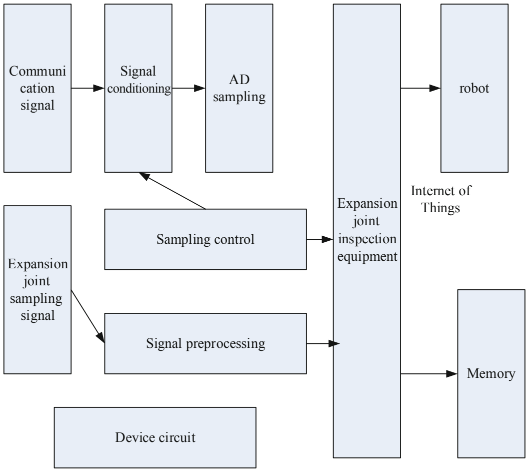

Fig. 2. Wireless device fault detection design framework

It can be seen from the above design framework that this device is mainly composed of a signal data acquisition part and a signal data analysis part. This device mainly uses a powerful ARM chip as the core of the design, and gradually realizes independent storage of signal data and signal data transmission, and realizes the task of detecting communication failures. The device is small in size, low in power consumption, and high in integration, which can effectively make up for the deficiencies of the original device.

In view of the characteristics of the Internet of Things technology, the communication between the signal data acquisition module of this device and the device is set through QTcpSocket. Therefore, in this design, an abnormal signal acquisition module suitable for the Internet of Things is set to realize the processing of abnormal signals. The robot integrated monitoring sensor is used to display the real-time communication status and data of the wireless robot in a unified device, and the data acquisition module designed this time is connected with the robot monitoring device. To ensure the effectiveness of this module design, set the hardware device parameters of this module as shown in Table 1:

Table 1. Signal collector parameter setting

Content	Parameter setting	content	Parameter setting
Signal driving	Digital signal	Interface Type	RS485
Interface form	Dry contact	Baud rate	1200–110 000 b/s
Form of protection	PPTC + TVS	Data bit	6
Protection level	600W	Stop bit	1
Overcurrent protection	30V/50 mA	Check Digit	even, odd
Collection form	1 kHz	Transmission distance	500 m

In this part, the LPC2131ARM microprocessor is used to realize the real-time acquisition and processing of robot signals. The device designed this time adopts the form of signal interruption and query to start collecting 00–11 of the signal sent by the robot. Develop the corresponding pre-processing of the collected signal, use wavelet transform to filter the signal data, and set it to a unified form to facilitate the subsequent processing and analysis of the signal data. To ensure the effect of signal acquisition, set the acquisition frequency of the acquisition device as follows:

$$y = a * b \tag{1}$$

In formula (1), y is the signal acquisition frequency, a is the robot communication signal transmission frequency, and b is the robot signal acquisition period. The frequency of signal acquisition is controlled by this formula. The memory interface of the monitoring device is set to a 64-bit width to improve the data storage capacity of the monitoring equipment, and the collected signals are uniformly transmitted to the memory of the monitoring device and processed in a unified manner.

2.3 Design a Signal Extractor Based on IoT Technology

The above-mentioned collected signals are preprocessed as data samples of abnormal communication signals, and the corresponding technology is used to complete the extraction of fault signals. In this part, by setting the form of the database analysis chip, the ability of data analysis and sorting is improved. This part adopts high-speed data computing chip as the carrier of equipment operation. Use the C-means clustering calculation method to complete the processing and analysis process of the fault signal [9], the algorithm is fast, simple, efficient for large datasets and scalable, set the signal of the device in the Internet of Things technology as the feature vector in the signal extraction process as y and set the signal data in the database as the signal analysis sample. $A = a_i$, $y = 1, 2, ..., n$, Set the signal category to be analyzed as z, y_i is z cluster center, and u_{iz} is the membership function of p signal, then the objective function of the communication signal classification is:

$$p_n = \sum_{i=1}^{z} \sum_{n=1}^{n} u_{iz} |a_i - y_i| \tag{2}$$

Set the elements in the above formula to be constant and greater than 1, then:

$$\sum_{n=1}^{n} u_{iz} = 1 \tag{3}$$

Setting the above formula as a constraint condition, the membership degree and clustering center of the collected signal can be expressed as:

$$u_{iz} = \frac{\left(1/|a_i - y_i|^2\right)^{1/(z-1)}}{\sum_{n=1}^{z} \left(1/|a_i - y_i|^2\right)^{1/(z-1)}} \tag{4}$$

Through the above formula, the central membership degree of the signal data sample can be obtained, and the signal sample can be divided into one or more data types. In this part of the design, the typical characteristics of communication signal failure types are set as the cluster center. When a data sample belongs to multiple communication data characteristics at the same time, this signal data is a failure signal. In order to ensure the effectiveness of clustering, the robot communication fault category is pre-selected and set in this chip.

3 Design a Data Acquisition Card for Fault Monitoring of Highway Bridge Expansion Joints

According to the output voltage, data acquisition channel and data analysis requirements of the current transmitter of the highway bridge expansion joint fault monitoring device, the PCI-6034E multi-function data acquisition card (DAQ). The PCI-6034E multifunctional data acquisition card has a resolution of up to 16 bits, with 16 single-ended or 8 differential analog input ports, and a sampling rate of up to 200 kS/s, which can meet the resolution requirements of data acquisition and data analysis; The read and write speed of the hard disk can be up to 200 kS/s, which can ensure the simultaneity of information collection and information processing; it can meet the requirements of voltage signal collection and fault detection and positioning accuracy of signal collectors and signal extractors: compatible with real-time System, Linux, Mac OS and Windows operating systems, integrated LabVIEW, LabWindows/CVI and Measurement Studio software development environment for Visual Basic and Visual Studio.NET, provide a platform for the monitoring device to implement fault detection and location algorithms; highly integrated It has a minimum volume specification, which can meet the requirements of industrial computer design integration.

In addition, the PCI-6034E multifunctional data acquisition card has a sample storage capacity of 512 [10], a single-channel current drive capacity of 24 mA, a maximum signal source frequency of 20 MHz, and a digital trigger and synchronization bus (RTSI). The performance provides a good hardware condition for the non-intrusive low-voltage power failure monitoring device.

GPRS DTU can realize the transparent transmission of serial device data through the GPRS wireless network, that is, just like a mobile phone, just insert the GPRS-enabled

SIM card and simply set the parameters, then the data of the external serial device can be transparently transmitted to the public network fixed domain name or IP At the same time, it can also receive feedback commands from the server on the host computer, which is especially suitable for the transmission of multiple points, multiple points, inconvenient wiring, and real-time data requirements. It is especially suitable for the transmission of multi-point scattered, inconvenient wiring, and real-time data transmission. However, the installation location of the device in this project is not convenient for wiring and connecting to the network, so the use of GPRS DTU communication equipment can meet the needs of this article [11–13]. The process of the data card transferring data to the software through the device is shown in Fig. 3:

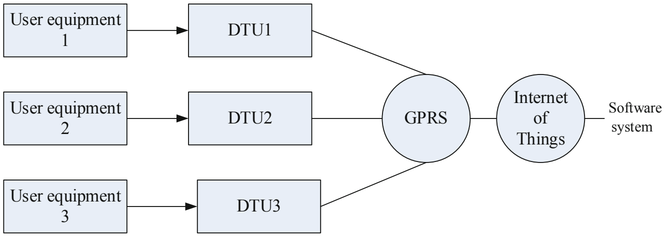

Fig. 3. The process of the data card transferring data through the device to the software

Considering the requirements of the acquisition card, the communication module uses the IQ1000 GPRS DTU communication equipment developed by Xiamen Lingqi Communication Co., Ltd. LQ1000 GPRS DTU provides a standard RS232/485 data interface, and has a built-in industrial-grade GPRS wireless module, which can be easily connected to RTU, PLC, industrial computer and other equipment, and only needs to complete the initial configuration at a time, and the user equipment can pass through the data center The GPRS wireless network establishes a connection and realizes the fully transparent transmission of data.

4 Case Analysis

In order to verify whether the road bridge expansion joint failure monitoring device based on Internet of Things technology designed in this article can meet the requirements of road bridge expansion joint failure monitoring, an example analysis method is designed, and the device designed in this article is used in actual detection to observe the monitoring effect. Verify the superiority of the method designed in this paper.

4.1 Project Overview

The span structure of Bridge A selected in the example is arranged as (south bank) approach bridge (5 × 40 m) + main span suspension bridge (820 m) + (north bank) approach bridge (6 × 40 m + 30 m). The bridge level is level 4, and the design safety level of the extra-lane expressway bridge is I level; the design load level is highway-I level, the design driving speed is 80 km/h; the crowd load: 2.5 kN/m2.

The bridge is a single-span steel box girder suspension bridge with a main span of 820 m, with a central buckle in the middle of the span; the sag-span ratio of the main cable in the completed state is 1/10, and the center-to-center spacing of the main cable is 29.1m; bridge deck width It is 29.78 m, and its layout is 29.78 m = sling anchorage area 0.84 m + sidewalk 1.78 m + anti-collision guardrail 0.52 m + carriageway 10.75 m + central divider 2.0 m + carriageway 10.75 m + collision guardrail 0.52 m + sidewalk 1.78 m + sling anchorage area is 0.84 m.

Under the action of temperature change, the long-span bridge structure is affected by the structural deformation and internal force caused by the temperature change. The research and analysis of the bridge temperature distribution through the health monitoring system can provide the original basis and data for the bridge design considering the influence of temperature, and the health monitoring system can provide temperature compensation and correction reference for the original data of other sensors. A study of temperature effects. Analyze and compare the operating conditions of bridges under the action of temperature changes, such as bridge structural disturbance changes, displacement changes, and component stress distribution changes, to verify and improve bridge design theory accurately and timely under the influence of actual temperature changes. Carrying out a safety assessment is of positive significance.

The highway bridge expansion joint failure monitoring device uses a structural temperature sensor to monitor and measure the structure temperature, and uses a temperature and humidity sensor to monitor and measure the temperature and humidity of the atmospheric environment. The structure temperature measurement points and data acquisition sequence are shown in Table 2:

The expansion joints are mainly set at the junction of the side span and the main span. Due to the large external environment effects such as vehicle load and temperature load, the Nanxi Yangtze River Bridge adopts a unit type multi-directional displacement bridge expansion device (RBQF1600). Expansion joint device is aimed at the problems and deficiencies of traditional modular expansion devices and comb expansion devices on large bridges such as suspension bridges and cable-stayed bridges. It has multi-directional displacement functions such as lateral displacement, longitudinal displacement and torsion in large bridges. And the new generation of bridge expansion devices developed under the influence of vehicle load on the expansion device itself. The service performance of this new type of expansion joint device still needs to be verified in actual engineering operations.

The monitoring of vehicle load is through the measurement of traffic flow, vehicle wheelbase, vehicle speed, vehicle weight, etc. of the operating bridge, and the measurement of these data is mainly carried out through vehicle speed and axle meters. By monitoring the vehicle load, it can provide data for the establishment of the vehicle load model of the bridge, and can provide a basis for evaluating the structural state. In addition, the analysis of the vehicle load spectrum can provide load parameters for the formulation of the fatigue load spectrum and the analysis of the bridge structure.

4.2 Analysis of Application Results

In this section, the influence of the change of ambient temperature on the temperature of the beam section of a bridge suspension bridge under normal operating conditions. In

Table 2. Structure temperature measurement points and data acquisition sequence

Collection location	Storage order	Measuring point number	Location
South Bank Approach Bridge	1	B05-DTH-001	Upstream
	2	B05-DTH-002	Upstream
	3	B05-DTH-003	Upstream
	4	B05-DTH-004	Upstream
	5	B05-DTH-005	Upstream
Main span suspension bridge	6	B05-DTH-006	Midstream
	7	B05-DTH-007	Midstream
	8	B05-DTH-008	Midstream
	9	B05-DTH-009	Midstream
	10	B05-DTH-0010	Midstream
North Shore Approach Bridge	11	B05-DTH-0011	Downstream
	12	B05-DTH-0012	Downstream
	13	B05-DTH-0013	Downstream
	14	B05-DTH-0014	Downstream
	15	B05-DTH-0015	Downstream

order to investigate the effect of the environmental temperature change of the bridge on the temperature of the beam section in the four seasons of the year, one day was selected in each of the four seasons, namely October 30, 2013 (autumn), January 16, 2b14 (winter), On April 16, 2014 (spring) and August 2, 2014 (summer), we analyzed the temperature data records of these four days. It should be noted that the structure temperature data is calculated with 1-min as the calculation interval, and the average value of all temperature sensors shown in Fig. 3 is taken as the effective value, then 1440 structure temperature data can be recorded every day. The structural temperature of the top, bottom, and web of the bridge is the average value of the sensors at their respective positions. The comparison chart of ambient temperature monitoring and actual temperature is shown in Fig. 4:

The experimental results shown in Fig. 4 show that the actual temperature detection result of the device in this paper is roughly consistent with the actual temperature change, indicating that the device designed in this paper has a high accuracy in detecting the temperature environment of the expansion joint failure. Temperature is a crucial factor for the expansion joints of Guiping Road Bridge. The change of temperature is directly linked to the failure of the expansion joints. Therefore, the accurate detection of temperature is very important for the failure monitoring of the expansion joints of highway bridges.

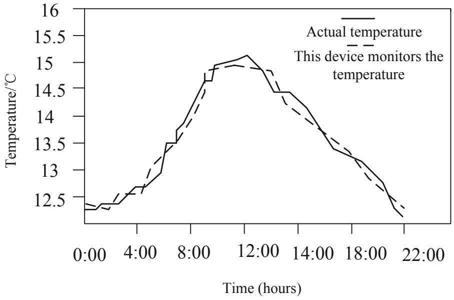

Fig. 4. Experimental results

5 Conclusion

This paper designs a fault monitoring device for highway bridge expansion joints based on Internet of Things technology. This model contains two main devices. The company's models and algorithms have been verified by on-site data, the fault signal acquisition equipment based on the Internet of Things technology is designed, the signal collector based on the Internet of Things technology is designed, and the signal extractor based on the Internet of Things technology is designed. Design for failure monitoring of highway bridge expansion joints Data acquisition card. Finally, through example analysis, it is proved that the detection accuracy of the highway bridge expansion joint failure monitoring device combined with the Internet of Things technology is very high, which meets the basic requirements of highway bridge expansion joint failure monitoring.

Fund Project. Nanjing Transportation Vocational and Technical College scientific research fund project (Project number: JZ2007), school-enterprise cooperation horizontal project fund project (Project number: 701920001).

References

1. Yang, L., Wang, G., Qin, S., Wang, Q.: A study on reconstruction algorithm of multi-bearing vibration signal based on DCS. Computer Simulation **36**(5), 316–319,324 (2019)
2. Liu, Y., Xiao, F.: Intelligent monitoring system of residential environment based on cloud computing and internet of things. IEEE Access, PP(99), pp. 1–1 (2021)
3. Zeng, J., Peng, C., He, P., Liu, C.: Research on current monitoring and fault diagnosis technology for control rod drive mechanism. Hedongli Gongcheng/Nuclear Power Eng. **40**(1), 172–175 (2019)
4. Gao, D., Wang, L.: An implementation of intelligent substation monitoring system based on internet of things. J. Comput. Methods in Sciences Eng. **19**(S1), 219–226 (2019)
5. Naman, H.A., Hussien, N.A., Al-Dabag, M.L., Alrikabi, H.: "Monitoring the consuming of electrical energy based on the internet of things applications" has been accepted for publishing after double blind review. Int. J. Interactive Mobile Technologies (iJIM) **15**(2), 172–183 (2021)
6. Ahouandjinou, M.H., Medenou, D., Pecchia, L., Houessouvo, R.C., Jossou, T.R.: Modeling an integrated network for remote patient monitoring, based on the internet of things for a more preventive and predictive health system in West Africa. Global Clinical Eng. J. **3**(2), 19–31 (2020)

7. Irawan, Y., Wahyuni, R., Muzawi, R., Muhardi, M., Hamzah, M.L.: Real time system monitoring and analysis-based internet of things (iot) technology in measuring outdoor air quality. Int. J. Interactive Mobile Technologies (iJIM) **15**(10), 224–240 (2021)
8. Qin, L., Xie, Y.: Real-time monitoring system of exercise status based on internet of health things using safety architecture model. IEEE Access **9**, 2733–27345 (2021)
9. Musyafa, A., Abadi, I., Noriyati, R.D., Mukromin, R., Asy'Ari, M.K.: Design and implementation monitoring system based internet of things (iot) on battery charging - photovoltaic power plant using flc. Int. J. Mechanical Mechatronics Eng. **20**(4), 22–30 (2020)
10. Kareem, O.K., Adekitan, A.I., Awelewa, A.: Power distribution system fault monitoring device for supply networks in nigeria. Int. J. Electrical Computer Eng. **9**(4), 2803–2812 (2019)
11. Liu, S., Liu, D., Muhammad, K., Ding, W.: Effective Template Update Mechanism in Visual Tracking with Background Clutter. neurocomputing, online first (2020). https://doi.org/10.1016/j.neucom.2019.12.143
12. Liu, S., Liu, X., Wang, S., Muhammad, K.: Fuzzy-aided solution for out-of-view challenge in visual tracking under IoT assisted complex environment. Neural Comput. Appl. **33**(4), 1055–1065 (2021)
13. Liu, S., Li, Z., Zhang, Y., Cheng, X.: Introduction of key problems in long-distance learning and training. Mobile Networks Appl. **24**(1), 1–4 (2018)