Smart Structures and Systems, *Vol. 21, No. 5 (2018) 611-621*
DOI: https://doi.org/10.12989/sss.2018.21.5.611

An integrated structural health monitoring system for the Xijiang high-speed railway arch bridge

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(Received December 2, 2017, Revised March 6, 2018, Accepted March 24, 2018)

Abstract. Compared with the highway bridges, the relatively higher requirement on the safety and comfort of vehicle makes the high-speed railway (HSR) bridges need to present enhanced dynamic performance. To this end, installing a health monitor system (HMS) on selected key HSR bridges has been widely applied. Typically, the HSR takes fully enclosed operation model and its skylight time is very short, which means that it is not easy to operate the acquisition devices and download data on site. However, current HMS usually involves manual operations, which makes it inconvenient to be used for the HSR. Hence, a HMS named DASP-MTS (Data Acquisition and Signal Processing - Monitoring Test System) that integrates the internet, cloud computing (CC) and virtual instrument (VI) techniques, is developed in this study. DASP-MTS can realize data acquisition and transmission automatically. Furthermore, the acquired data can be timely shared with experts from various locations to deal with the unexpected events. The system works in a Browser/Server frame so that users at any places can obtain real-time data and assess the health situation without installing any software. The developed integrated HMS has been applied to the Xijiang high-speed railway arch bridge. Preliminary analysis results are presented to demonstrate the efficacy of the DASP-MTS as applied to the HSR bridges. This study will provide a reference to design the HMS for other similar bridges.

Keywords: high-speed railway; structural health monitoring system; wind characteristics; cloud computing

1. Introduction

Health monitoring system (HMS) can be used to validate design assumptions and computational methods, detect anomalies in loading and response, and possible damage/deterioration at an early stage, offer real-time information for safety assessment immediately after disaster and extreme events, provide evidence and instruction for planning and prioritizing bridge inspection, rehabilitation, maintenance and repair, and obtain massive amounts of in-site date for leading-edge research in bridge engineering (Ko *et al.* 2005, Wenzel *et al.* 2009, Zhou *et al.* 2016). Bridge health monitoring system has become an important element for bridge management and maintenance (Li *et al.* 2006, Wang *et al.* 2014, Seo *et al.* 2015, Koo *et al.* 2016). Recently, the health monitoring system has been installed on a number of bridges, including the Akashi Kaikyo bridge in Japan (Sumitro *et al.* 2001), the Oresund bridge in United States (Peeters *et al.* 2003), the Tsing Ma bridge (Wong 2004) and Sutong bridge in China (Wang *et al.* 2016a; 2016b), the Great Belt bridge in Denmark (Andersen *et al.* 1994, Frandsen 2001), and the Hwamyung bridge in South Korea (Huynh *et al.* 2016). The abovementioned studies, however, were concentrated on the long-span highway bridges, while relevant researches on the railway bridges are very limited. The major reason may be that the span of most of railway bridges is very small resulting in insignificant effects from the running train. With the development of high-speed railway (HSR) throughout the world, more new high-speed railway lines will be constructed or put into operation in the next decade (Hu *et al.* 2014, Yan *et al.* 2015). For example, the HSR will be gradually constructed toward the western mountains and east coast areas in China, and hence the HSR bridge towards large span is inevitable (He *et al.* 2017). On the one hand, facing more complex terrain, the probability of train being subjected to extreme events such as strong winds and earthquakes will increase (He *et al.* 2016). On the other hand, HSR puts forward higher requirement on the safety and comfort of trains (He *et al.* 2017). Therefore, it has become a consensus that a HMS needs to be installed on selected key bridges in order to ensure the safety of train operation (Ding *et al.* 2015a, 2015b, Kim *et al.* 2016).

The HSR takes fully enclosed mode and the skylight time is short, which means that it is not easy to operate the acquisition devices and download date on site. Hence, the HMS installed on the HSR should collect and upload data automatically with enough storage space. Additionally, the HMS should also have the ability to timely share data with experts from various locations for the most effective and in-time response to the unexpected events. Whereas it is well

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http://www.techno-press.com/journals/sss&subpage=7 ISSN: 1738-1584 (Print), 1738-1991 (Online)

known that the current HMSs present difficulty to deal with big data using the desktop computers and to timely share real-time data with other experts (Necati *et al.* 2008, Wang *et al.* 2016a). Also, there is a lack of professional skills to deal with massive measured data in field data acquisition station. The application of wireless smart sensors and wireless network to the HMS in recent years facilitates easier installation and low cost, however, it is still hard to cope with the big data (Cho *et al.* 2010, Jang *et al.* 2010). In a sense, the wireless technique only focuses on the data transmission, while the improvement of calculation and analysis at the data workstation is still very limited. On the other hand, the cloud computing has been attracting great attentions in various fields with the rapid development of computer technology (Zhang *et al.* 2010, Khan 2016). As a high-performance and friendly-computing technique, cloud computing has been actually widely utilized in the weather forecast (Skamarock and Klemp 2008), intelligent traffic (Li *et al.* 2011) and energy management (Beloglazov *et al.* 2011). However, its application to HMS has been rarely reported and how to utilize its strong computing power to enhance the current HSM is worthy of study. Therefore, the combination of cloud computing and wireless network techniques may offer a promising way to make full advantage of the strong computation ability and high-performance data transmission (Yi *et al.* 2014, Li *et al.* 2015, Jeong *et al.* 2016, Li *et al.* 2016).

This study focuses on the development of an online HMS, DASP-MTS (Data Acquisition and Signal Processing - Monitoring Test System), which integrates the internet, cloud computing (CC) and virtual instrument techniques. Compared with the existing HMS, one of the greatest strengths for DASP-MTS is that it effectively integrates the CC and wireless internet techniques, and hence the data acquisition and transmission could be automatically realized and the deep-level signal processing can also be achieved. As a result, the users can obtain real-time data and assess the health situation using a terminal at any location. In order to demonstrate the efficacy of the DASP-MTS, a high-speed railway Xijiang bridge is introduced as the case study.

2. DASP-MTS (Data Acquisition and Signal Processing - Monitoring Test System)

2.1 General framework of DASP-MTS

In comparison with traditional HMS, DASP-MTS has been acquired great improvements in the testing method, the ability of calculation and the working pattern. By integrating the internet and CC technique into the DASP-MTS, the traditional regional restriction is broken while the computational capability is enhanced to great extent. On the one hand, users can obtain the real-time health situation via the internet without the limitation of time and space. On the other hand, users can effectively process and manage the big data with the clouding computing center. Also, the acquisition devices can automatically realize the modulation and collection of signal using built-in microprocessors and customized software by introducing the VI technique. Furthermore, the users can complete various signal processing and analysis without installing any software on the terminal using the CC-based DASP-MTS. For each assignment, users simply need to request related service according to their demand, which changes the traditional working pattern. A general topology structure of DASP-MTS is illustrated in Fig. 1. As shown, the sensors and acquisition devices are distributed at various sites for different monitored structures and the front-end acquisition hardwares located at various locations were synchronized based on the GPS or Beidou satellite system. The initial data will be transmitted to the CC center, and the recorded data will be processed using testing service software. Finally, the measurement results will be provided and returned to the users. Also, the users can send necessary commands to CC center to control the front-end hardware.

In general, DASP-MTS mainly consists of three parts including front-end acquisition hardware, back-end cloud computing center and terminal devices.

Front-end acquisition hardware. Front-end acquisition hardware include various sensors and virtual acquisition instruments. The sensors are used to capture target static and dynamic signal, while the virtual acquisition instruments are basically employed to control, receive and preprocess measured signal from sensors with embedded system. Pre-processed original data such as the mean, standard deviation, maximum and minimum together with all the original data will be transmitted to cloud center.

Back-end cloud computing center. Back-end cloud computing center is the core for the DASP-MTS, which is responsible for coordinating the entire system. Firstly, the center receives the measured raw data and pre-processed data from front-end acquisition hardware. The data will be subsequently classified into several categories according to the source of signal. Secondly, deep-level data processing and integration will be carried out using a number of modern signal process schemes. Deep-level structural health situation information could be discovered with the use of cloud computing technique. This step is essential to reduce the vast amount of data into the applicable information for structural health evaluation. Finally, the extracted information will be fed back to the administrator; the suggestions of management and maintenance will be provided.

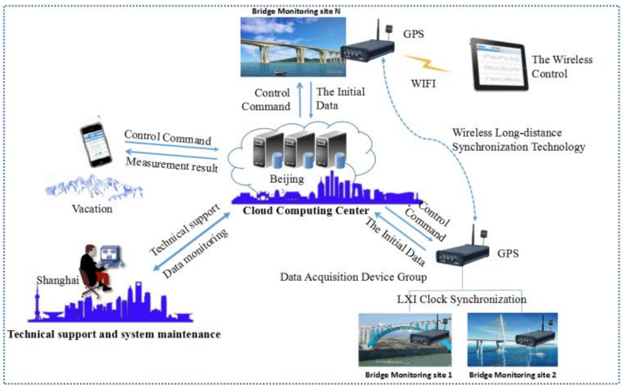


Fig. 1 A general topology structure of DASP-MTS

Fig. 2 The login interface of DASP-MTS

Fig. 3 Home page of the user interface

Terminal devices. Terminal devices are the last part of DASP-MTS which is used to manipulate the front-end hardware and receive the obtained testing information from cloud center. Since the Browser/Server (B/S) frame is adopted into DASP-MTS, technicians from different areas could access to the cloud center simultaneously using the terminal devices. It is a great convenience for the users to deal with unexpected events. The login interface of DASP-MTS is shown in Fig. 2. Two different register permissions were designed, namely user and administrator. The administrator can examine and modify the source code, and further develop the system according to the requirements, while the users simply look over the real-time signal and set some basic parameters for the front-end acquisition hardware. After logging into the system, home page of the user interface will be used to operate and control the entire system, as presented in Fig. 3.

2.2 Major components of DASP-MTS

The structure of DASP-MTS is divided into four modules, namely sensory subsystem (Module 1), data collection and transmission subsystem (Module 2), data management and control subsystem (Module 3), and structural evaluation subsystem (Module 4) (Ni *et al.* 2009, Ni *et al.* 2011, Wang *et al.* 2016a, Zhou *et al.* 2016). Modules 1 and 2 are located at the structure site, while Modules 3 and 4 are embedded in the cloud center. The architecture of the DASP-MTS is shown in Fig. 4.

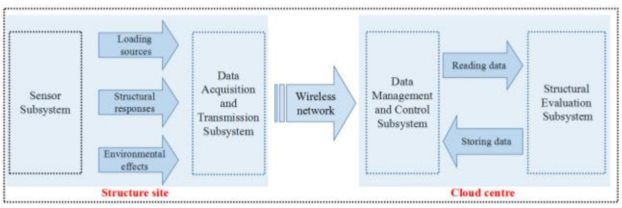


Fig. 4 Architecture of the DASP-MTS

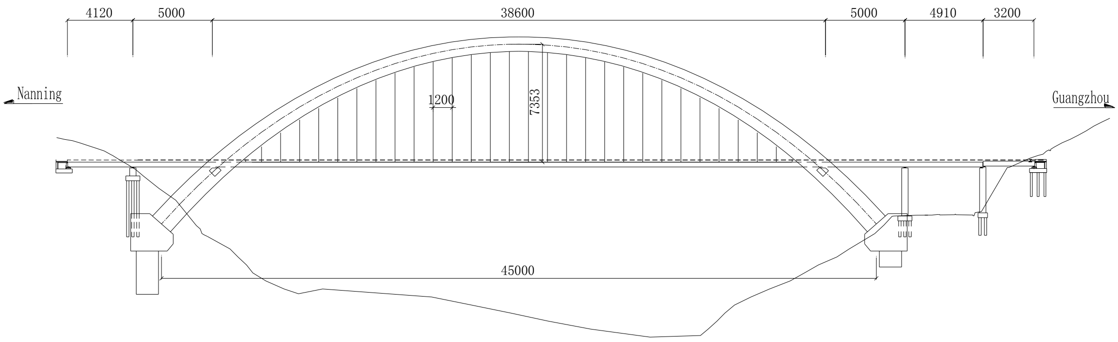
Sensory subsystem (SS) is the most fundamental and vital element in the system, which are mainly employed for monitoring three types of parameters: (i) loading sources such as wind, seismic, traffic and ship collision; (ii) structural responses such as static strain, dynamic strain, displacement and acceleration; (iii) environmental effects such as temperature, rain and corrosion (Ni *et al.* 2009). Types and locations of sensory systems should be designed to capture the local- and general-level response, and be able to immediately collect accidental ambient loading such as typhoon, earthquake and ship-collision.

Data acquisition and transmission subsystem (DATS) consists of acquisition instruments, transfer cable wire, industrial wireless routers, distant cloud database and users' terminals. It is the controller for the data collection in sensory subsystem. Also, it should be able to successfully transmit the acquired data to DMCS. To improve signal-to-noise ratio, shield cable is usually employed to transmit the signal from the sensors to the acquisition instruments. Furthermore, all cables are protected by the polyvinyl chloride (PVC) pipes to achieve the long-term reliability. It is worth noted that the transmission wires could be divided into several parts to shorten the transmission distance and hence reducing the impacts from electromagnetism and long-transmission. Each part could be equipped with a data acquisition instrument, and all these acquisition instruments need to be synchronized.

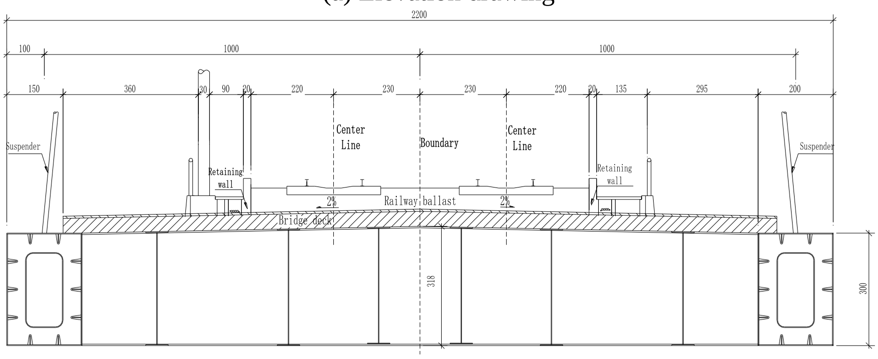
Data management and control subsystem (DMCS) is the central system of the DASP-MTS. It is the connection element between DATS and structural evaluation subsystem. The DMCS not only receives data from DATS, but also provides applicable information for the structural evaluation through a number of pre-processing and post-processing. In the DMCS, the data will be classified and archived into several databases at first. Subsequently, data processing will be proceeded and the applicable information will be extracted from the massive original data under integrated self-developed programs and modern mathematical algorithm like short-time Fourier transform (STFT), wavelet transform (WT) and Hilbert-Huang transform (HHT) (Yu *et al.* 2005, Li *et al.* 2007). For example, the measured modal properties such as natural frequencies, mode shapes and modal damping ratios are identified from the accelerations of the main components using frequency domain decomposition (FDD) and stochastic subspace identification (SSI) methods (Cho *et al.* 2010); the wind spectrum model for the bridge site is obtained from the analysis of the strong wind data samples; the thermal field of the bridge site is established from long-term monitoring of the temperature distribution (Wang *et al.* 2016a) . DASP-MTS has powerful computational ability in on-line and off-line data processing based on the cloud computing. At present, it is able to carry out hundreds of signal processing methods including auto-correlation, cross-correlation, mode analysis and resonance demodulation analysis.

Structural evaluation subsystem (SES) is the core of the DASP-MTS, which can provide administrators with structural health situation information and necessary suggestions of management and maintenance. Another important function of SES is to forecast future structural

Fig. 5 Location of Xijiang bridge.



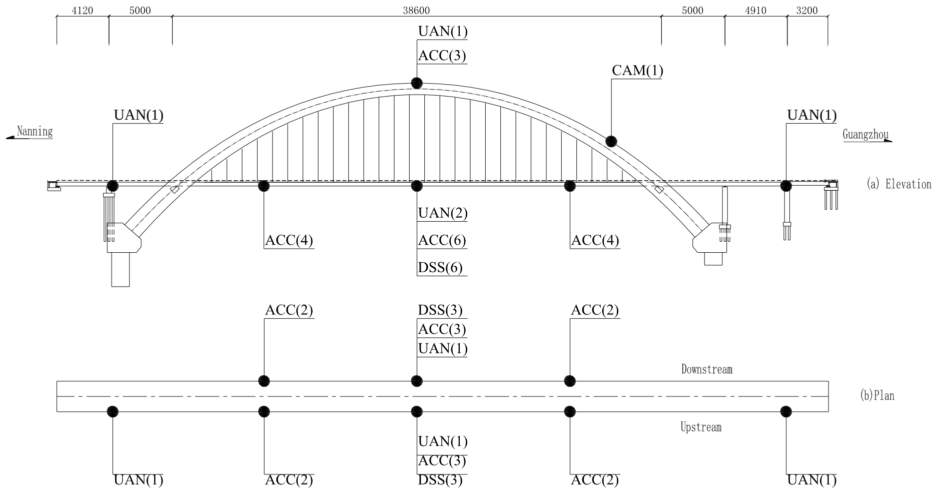
(a) Elevation drawing



(b) Design drawing of the deck cross-section

Fig. 6 The geometry of Xijiang bridge (unit: cm)

performance by measuring the current state, estimating the future loading environment, and deep-level estimation of remaining life time of the structure. It mainly includes five evaluation levels, namely application evaluation, structural ranking evaluation, durability evaluation, damage detection and prediction evaluation, and safety evaluation (Wang *et al.* 2016a). The first part focuses on the evaluation of measured actions and response under extreme cases such as strong typhoons and earthquakes. The rest four parts work for the bridge management and maintenance. DASP-MTS is composed of online and offline evaluation parts. The online evaluation part is utilized in the application evaluation for the extreme environment to offer the effective information in time. The process is achieved by comparing the measured loading or response with the pre-defined thresholds (Zhou *et al.* 2016). When the measured results exceed the pre-defined thresholds, the system will send a warn message to the users in the form of an email or a text (Wang *et al.* 2014, Zhou *et al.* 2016). While the offline evaluation is used for the latter evaluation parts. The structural ranking evaluation aims to rank the components of structure by their importance, fatalness and vulnerability based on the finite element analysis. The durability evaluation focuses on evaluating the corrosion status of steel in concrete, cable, suspender, and the abrasion of bearings. The damage detection and prediction evaluation is used to evaluate the



UAN: ultrasonic anemometer; CAM: camera; ACC: accelerometer; DSS: dynamic strain sensor

Fig. 7 Deployment of sensors on Xijiang bridge (unit: cm)

component, joint and structural damages and provide the reference and suggestions of structural performance for maintenance. For the safety evaluation part, it aims to comprehensively estimate the overall health status of component and whole structure. If all the evaluations present positive feedbacks, the structure is determined to be qualified to continue the service, otherwise some inspections and maintenance need to be conducted (Wang *et al.* 2016a). To more effectively evaluate the health situation, the risk forecast indexes and thresholds should be predefined based on the numerical simulations and/or experimental investigations.

3. Implementation of the DASP-MTS on Xijiang bridge

3.1 Xijiang bridge

Xijiang bridge is a half-through steel box X-arch railway bridge carrying double-lines across the Xijiang River. It belongs to a key project for the Nanning-Guangzhou high-speed railway (see Fig. 5), located between Wuzhou, Guangxi autonomous region and Zhaoqing, Guangdong province in China. The main span is 450m ranking at the top of its type with 1/4 rise-span ratio, as shown in Fig. 6. The width of deck is 22 m, and the height from deck to vault is 73.53 m. The bridge deck system is composed of vertical and horizontal steel beam with RC beam bridge panels. The size of steel box arch rib section is 15×5 m. The suspender system of the Xijiang bridge consists of high strength and low relaxation parallel wire bundle. There are totally 56 suspenders. The distance between two suspender unites is 12m along the longitudinal axis of the bridge deck. The designed train running speed on the bridge is 200 km/h, while reserved for 250 km/h. The construction of the bridge was started in November 2008 and ended in December 2014.

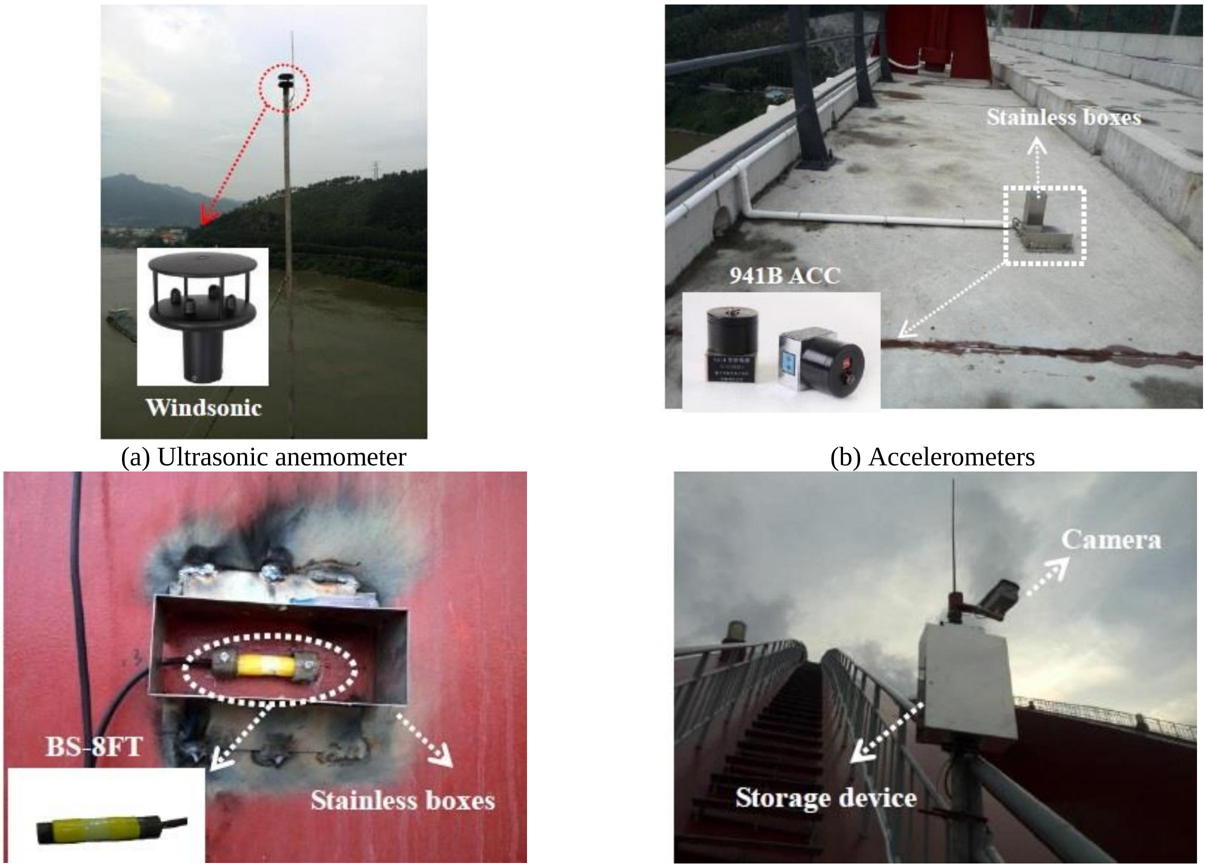
3.2 Deployment of sensors and acquisition instruments

3.2.1 Sensors

Considering the characteristics of the arch bridge and the limited available budget, wind environment, dynamic stress, vibration and video were selected as monitoring targets for the Xijiang bridge. Other monitor types such as suspenders cables force and displacement of deck will be easily added into the system if necessary. The nominal accuracy of all sensors were verified to guarantee the high testing precision. The deployment of overall sensory subsystem on the Xijiang bridge is shown in Fig. 7. The value in parentheses in the figure represents the quantity of sensors. Selected pictures of sensors implemented on the Xijiang bridge are shown in Fig. 8.

Since Xijiang bridge is located in the subtropical monsoon region and close to coastline, wind is a major loading source. Five 2D ultrasonic anemometers (UAN), Windsonic made by Gill company in UK, were installed on both ends of deck (Guangzhou and Nanning sides), mid-span deck (both upstream and downstream sides), and at the top of arch [Figs. 7 and 8(a)]. The wind speed resolution is 0.01 m/s with the sampling frequency of 1 Hz. The maximal wind speed measurement of the Windsonic is 60 m/s

For the dynamic actions, the vibration testing was employed to analyze the natural frequencies, damping ratios, and mode shapes of the entire structure. Also, it was used to detect the general damage location (Li *et al.* 2007, Cho *et al.* 2010). Totally, there are 17 uni-axial accelerometers (ACC) distributed on the deck and at top of arch. Three tri-axial ACCs were installed on mid-span deck (upstream and downstream) and at the top of arch. A tri-axial ACC is comprised of three uni-axial sensors placing in vertical, lateral, and longitudinal axes. The longitudinal is not taken into account for the bi-axial ACCs. The locations at the quarter-span and three quarters-span of deck on upstream and downstream sides were equipped with bi-axial ACCs.



(a) Ultrasonic anemometer (b) Accelerometers

(c) Dynamic strain sensors (d) Camera

Fig. 8 The site layout of sensors on structure

In order to reduce impact from the external environment, the ACCs were first welded on the surface of steel plates, and then they were covered by stainless boxes and sealed with a sealant, as displayed in Fig. 8(b). The Mode 941B ACCs, manufactured by Zhengheng Technology Company in China, were selected. It has four shifts containing acceleration shift, large-, medium-, and small-speed shifts. The medium-speed shift was employed to record the vibration for the Xijiang bridge. The sampling time length is 60s with the frequency of 51.2 Hz.

Local fatigue damage is more easily induced under non-periodic cyclic loading action in the long term. Xijiang bridge is a steel structure that is suffered from repeated train loading. Since strain is a key local parameter to reflect the structural performance in a more refined level (Wang *et al.* 2016a), the dynamic strain monitoring is a necessary. The mid-span section was selected as the key section. Six dynamic strain sensors (DSS), model BS-8FT made in Japan from KYOWA company, were symmetrically distributed on the mid-span deck. The strain sensors are able to simultaneously measure strain and temperature. Furthermore, it is designed with self-temperature compensation to eliminate the influence of environment temperature. The rated capacity of BS-8FT is ±1000 μm/m, and the safe temperature range is from -30℃ to 80℃. The shielded stainless boxes were also used to protect the strain sensors, as shown in Fig. 8(c).

According to the requirement of bridge managers, a video monitoring system was laid on the arch above 20 m from the deck at Guangzhou side. A high-resolution camera, SONY700, was used as part of the HMS, as shown in Fig. 8(d). The video monitoring system can directly observe the status of deck and track when the bridge suffers strong wind or the train runs on the bridge. Also, it improves the visual degree of health monitor system.

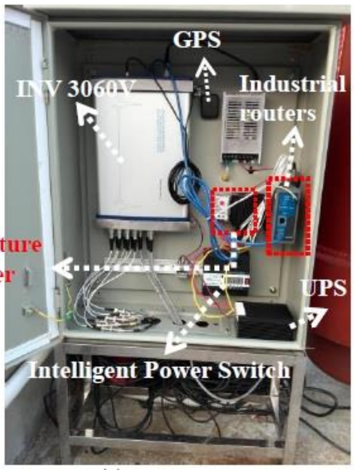
3.2.2 Acquisition instruments

The entire DATS is divided upstream and downstream parts. All the sensors distributed on the upstream/downstream decks were centralized around the base station. The IEEE1588 protocol LXI-class, a standard clock synchronization technology was adopted (Peng *el al.* 2009). In the HMS of Xijiang bridge, the high-performance front-end acquisition devices, INV 3060V, was employed. This device is designed with multiple embedded processors including FPGA (Field Programmable Gate Array), ARM (Advanced RISC Machines, RISC-Reduced Instruction Set Computer) and DSP (Digital Signal), which can realize off-line measurement, automatic identification of the sensor types, automatic completion of high-precision calculus analysis for the real-time signal (Yang *et al.* 2006, Jamro *el al*. 2012). Due to the ARM processor embed into the device, working parameters and control commands can be fully controlled via the internet, which meets the intelligent requirements of HMS for the HSR bridge (Yang *et al.*

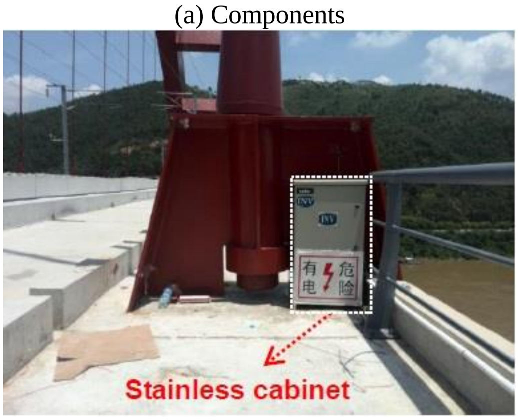
2006). In order to assure the durability of acquisition devices and the working stability of acquisition devices, several measures were taken for each base station. For examples, a lightning-proof stainless cabinets was used as an outermost protection. Also a temperature controller was fixed to ensure the acquisition device works in a thermostatic environment. Additionally, an intelligent power switch was installed in the cabinet, which aims to avoid the apparatus burning out due to instantaneous high voltage. An uninterrupted power supply (UPS), which protects the base station components from an unexpected electric surges and outages, was employed as well. The base station and its components are shown in Fig. 9.

3.3 Field measurement results

The HMS was established in August 2013. The system has been in good condition since its installation. A successful early-warning was observed on June 21th, 2015 when the typhoon Kujira attacked the bridge site. The information was timely return to the bridge managers, and the measures were implemented in time to guarantee the train running safety on the bridge. The reliability of DASP-MTS was verified in this event. In this section, the wind environment monitoring and vibration monitoring are selected to further demonstrate the efficacy of the HMS.



(a) Components



(b) Stainless cabinet

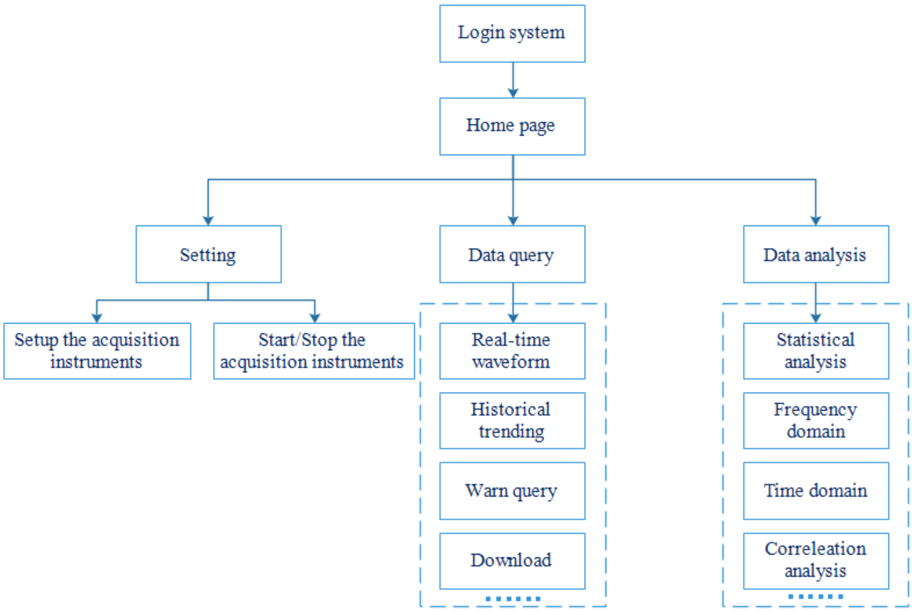
Fig. 9 The base station

(i) Wind environment monitoring. Based on the Xijiang bridge project, several customized subprogram were designed and implemented in the DASP-MTS, which can timely realize 10-min mean wind-speed and wind direction. In addition, three-level warn lights were set up according to various wind speeds. Wind samples are firstly transmitted to the CC center, and then are effectively managed under the DASP-MTS. Users input the website address using an internet browser, which facilitates ease acquirement and analysis of the real-time uploaded samples online. Data query and data analysis are two main functions of DASP-MTS. For the data query, five core parts are organized where users can view the time histories of wind speed samples, check the historical trending in a certain period, inquire the warn situations, download the original data for post-processing and produce a wind characteristic report in term of site terrain. For the data analysis, it focuses on providing various data online processes such as statistical, auto-spectrum and correlation analyses between different monitor locations. The processing flow of wind data in the DASP-MTS is shown in Fig. 10.

A large amount of wind speed data has been recorded since the HMS initiated including the Typhoon Kujira in June 2015 (He *et al.* 2017), as shown in Fig. 11. As shown, the changing of wind speed during the typhoon was quite distinct and the maximum instantaneous wind speed was larger than 20 m/s. While the typhoon is a special case for the bridge managers since special measures such as speed limit may be adopted, the wind characteristic in normal climate is the vital resource to obtain the extreme wind speed at the bridge site. Also, it provides significant references to study the train-bridge coupled vibration system subjected to the wind action (Xia *et al.* 2008). Therefore, the wind characteristic was analyzed based on the long-term measured data. Figs. 12(a)-12(c) illustrate the statistical results of mean wind speed, wind rose map and power spectral density (PSD). It is noted that the mean wind speed and wind rose are based on two-year wind measurement data and the PSD was obtained from a strong wind with a two-hour duration. It can be seen from these figures that the wind speed in normal climate at the Xijiang bridge is relatively low. The maximum wind speed is mainly from S, NNE, NNW directions, with the wind direction frequencies of 29.6%, 12.5% and 21.1%, respectively. In the PSD, a comparison with the Karman spectrum is shown. Generally, Karman spectrum is in good agreement with the measured one. The discrepancy between the empirical and measured PSDs may be due to the modifications from surrounding terrains.

(ii) Vibration monitoring. The vibration data is mainly utilized in modal parameters identification (He *et al.* 2011), the verification of existing analytical theory and updating the finite element model (FEM) (He *et al.* 2008). The processing procedure of vibration data using DASP-MTS is similar to the wind data case,as shown in Fig. 10, although the specific signal processing methods are different. At present, there are 82 trains running on the Xijiang bridge every day. Fig. 13 illustrates the bridge response when a high-speed train, CRH2A (China Railway High-speed 2A), runs on the bridge. As shown in the figure, the ACC can

(a) Graphical user interface



(b) flowchart

Fig. 10 The processing flow of wind data using DASP-MTS

accurately capture vibrating signals, and the vibration trends is also in accord with the fact that the primary vibrating is from vertical direction while the vibrating in lateral is minimum (Xia *et al.* 2005). In general, the response is small due to the large stiffness of bridge. According to the Fig. 13(b), the maximum displacement in vertical, lateral, longitudinal directions are 0.810 mm, 0.021 mm and 0.605 mm, respectively. Furthermore, the frequency identification is carried out using various methods including peak-picking (PP) (Fig. 14(a)) and stochastic subspace identification (SSI) (Fig. 14(b)) (Yu *et al.* 2005, Li *et al.* 2007, Cho *et al.* 2010). The identified results are compared with the values by FEM as listed in Table 1, and the good agreement has been achieved.

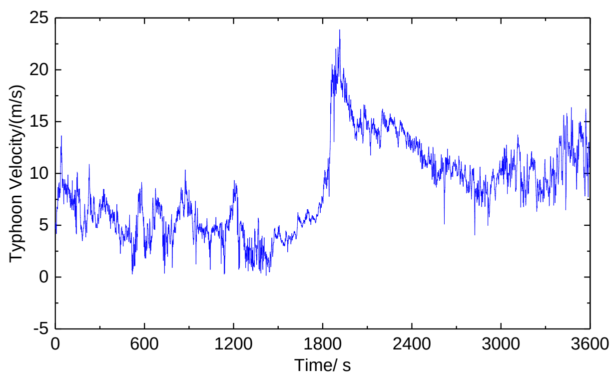
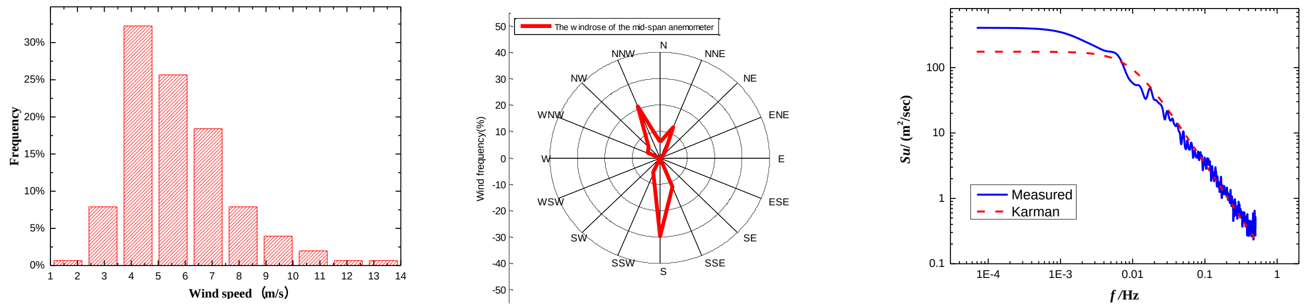
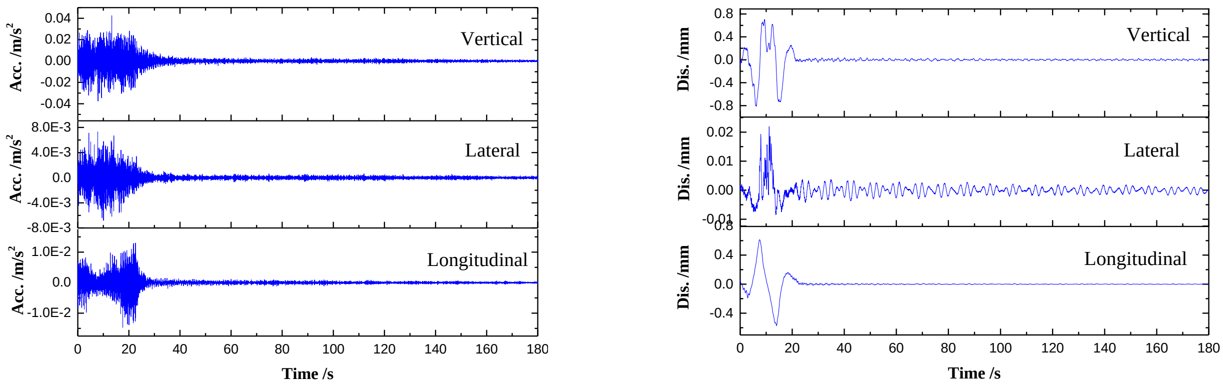


Fig. 11 Typhoon wind sample



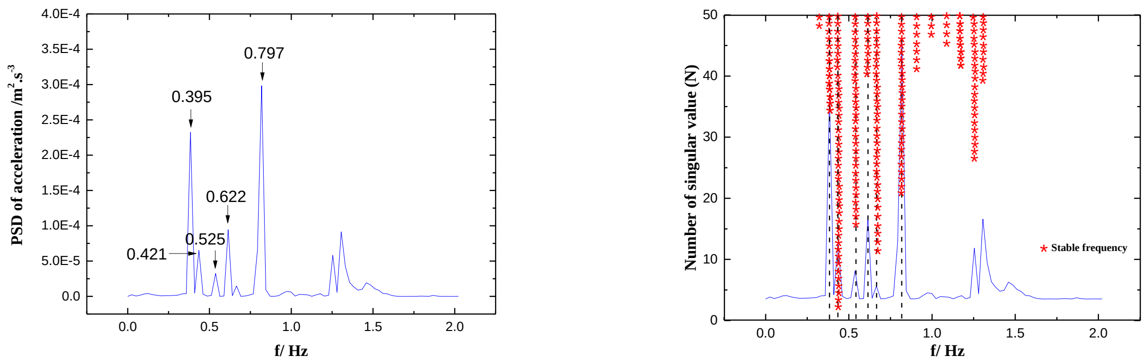
(a) Statistical result of mean wind speed (b) Wind rose map (c) Power spectral density

Fig. 12 Field measurement of wind environment



(a) Acceleration (b) Displacement

Fig. 13 The measured response at the mid-span as the train runs on the bridge



(a) PP (b) SSI

Fig. 14 Model identification

Table 1 Frequency identification using various methods

Mode No.	Frequency			Mode type
	PP	SSI	FEM	
1	0.395	0.391	0.408	The 1st symmetric lateral bending of the beam
2	0.421	0.415	0.423	The 1st anti-symmetric vertical bending of the arch
3	0.525	0.525	0.532	The 1st symmetric lateral bending of the beam
4	0.622	0.627	0.618	The 1st anti-symmetric lateral bending of the arch
5	0.797	0.790	0.756	The 1st symmetric vertical bending of the beam

4. Conclusions

Cloud computing is applied to the health monitoring of high-speed railway bridge, which makes the data transmission and storage more convenient. Collected data can be transferred to center cloud services via wireless network without installing any software. Users at any location can obtain the real-time monitoring results from the system since it can realize remote monitoring. The system can also automatically operate and perform a number of functions. The developed DASP-MTS online monitoring in a Browser/Server frame is more suitable for high-speed railway compared to the conventionally utilized health monitoring system. The DASP-MTS of the Xijiang bridge has been in good condition since its installation. The efficacy of HMS on the Xijiang bridge is verified by preliminary monitoring results from wind environment monitoring and vibration monitoring.

Acknowledgments

The work described in this paper was supported by grant s from the National Natural Science Foundations of China (U1534206) and National Key R&D Program of China (2017YFB1201204).

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