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Towards a cloud-based data visualization system for online condition assessment of in-service high-speed train

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ABSTRACT

In this study, we develop a cloud-based data visualization system for online condition monitoring and assessment of in-service high-speed train. The objectives of the system are (1) to monitor in-service data from different monitoring sites of instrumented high-speed trains and rails; (2) to conduct frequency response transfer function (FRTF) analysis on the data to assess the in-service train conditions; and (3) to provide a world-wide assessable channel for assessing and visualizing analytical findings. These functions are realized by establishing a cloud-based data visualization and analysis system with several software modules: (1) a networking system to transmit data from remote sites to the cloud; (2) a cloud-based database that allows data updating and management of the monitored data; (3) a visualization module embedding data processing algorithms and train drawing commands. In addition, the preferable data sampling rates is defined to balance the efficiency and accuracy of the data processing. For verification purpose, performance of the system is demonstrated using the monitoring accelerations and videos data acquired from varies components of an in-service train running on a China high-speed railway.

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1. INTRODUCTION

High-speed trains often produce significant vibration when running on tracks. This vibration is a direct reflection of the dynamic interactions occurring between train components and tracks. When vibration of the train becomes intense due to changing speeds, axle loads and track conditions, unexpected dynamic behaviour of the train components occurs, reflected in dynamic interactions between vehicle-substructures. As a result, the safe operation of trains is affected and the ride comfort of passengers cannot be guaranteed. Eventually, any irregular and unexpected behaviour of train components results in reduced service lives and lower train ride quality (Lei and Noda 2002). Hence, it is necessary to investigate the dynamic interactions between of high-speed train vehicle substructures under in-service conditions.

Since the measured acceleration changes of the train components and sub-components collected through the instrumented monitoring system provides authentic information relating to vehicle-substructure dynamic characteristics, the acceleration time history is of great interest and relevance to this study. It is able to conduct condition monitoring of train components based on accelerations obtained from in-service high-speed train.

However, as different high-speed trains run between various urban and suburban areas, it is difficult for individual experts to simultaneously supervise, analyse and make decision for the conditions of in-service trains. In view of this challenge, a more favourable solution is to upload those monitoring data from different sites to a central online monitoring and data analysis system providing accessibility for all authorized experts to observe data characters, develop corresponding indicators and make decisions. The concept of this online condition monitoring solution can be realized by employing an advanced cloud-based system (Wang and Liu 2015). A cloud-based system is able to update and process monitoring accelerations by integrating algorithms.

The study of this paper proposes and verifies a cloud-based data visualization system for data visualization and analysis. Firstly, an overview of the propose framework for the data visualization system built on cloud is presented. The system is for exploration of the vehicle-substructure dynamic interactions on high-speed trains, and adopts time-domain and frequency-domain analyses are performed on the dynamic responses collected from the axlebox, frame and carriage body. These algorithms are integrated into a developed cloud-based system for condition monitoring purpose. Subsequently, the study explains the design of some important modules. The system performance is then verified through the monitoring accelerations of an in-service high-speed train. Results show the feasibility and applicability of this system for condition monitoring.

2. OVERVIEW

The framework of the cloud-based monitoring system is shown in Fig. 1. The system mainly comprises Databases, Data analysis, Data visualization and User interface modules which are all built and operated on an appropriate public or private cloud platform. The Databases receives monitoring data (e.g. acceleration, strain, video, and location data) as inputs and outputs raw featured data. The Databases adopt matrix structure for data storage: different types of data are separately stored in different databases (Database, type I; Database, type II; etc.) for rapid data extraction; for a large volume of a same type of data, they are divided and stored at same parallel sub-databases for more effective calculation. The Data analysis modules take the raw featured data from the Databases as inputs. With it, the Data analysis modules integrate useful algorithms to process the raw featured data, being able to show features of raw data in both temporal and special dimensions, and have extracted features (e.g. peaks, cross-spectrum, damage factors, ride comfort indexes, etc.) from the raw data. The Data visualization module receives the extracted data features from the Data analysis modules as input, and then demonstrates it with illustrations by operating feasible drawing software on cloud. To facilitate internet users to access, view and control the monitoring system, a User interface module is set to (1) control the Data analysis modules to launch different algorithms for various analysis purposes, (2) receive and display the analysis results from the Data visualization module, and (3) provide download channel for system users to store the useful analysis results. The Data visualization module is compatible to the computing systems of laptop, PAD and Mobile. The whole system is operated on cloud platform. World-wide users can have access to and control the cloud-based data visualization system through internet.

Based on this framework, it is able to design a cloud-based data visualization system towards the application on high-speed train projects. The following chapter elaborates design of some important modules of the system.

3. DESIGN OF CLOUD-BASED DATA VISUALIZATION SYSTEM

3.1 Employment of applicable algorithms for data visualization system

The system is designed by integrating useful algorithms relating to acceleration (as input data) analysis for high-speed train, as the information extracted from acceleration data contains valuable information which will be further used for understanding the dynamic behavior of a train, such as interactions of different train components (Wang et al. 2016), and characteristics of train behaviors while running on different subgrades (Zhang et al. 2016).

Some widely applied algorithms for analyzing the original acceleration data include time domain and frequency domain analysis, and FRTF analysis of the accelerations of different sensors. In the following, the algorithms to be complied into the cloud-based system are introduced.

<u>In-service monitoring acceleration data and power spectrum density analysis</u> The condition monitoring procedure begins by identifying the acceleration amplitudes in both time and frequency domains. Data obtained from monitoring sensors is by default shown in time domain. The acceleration time history is also transformed to frequency domain using fast Fourier transform (FFT) technique for obtaining more information about the train component condition.

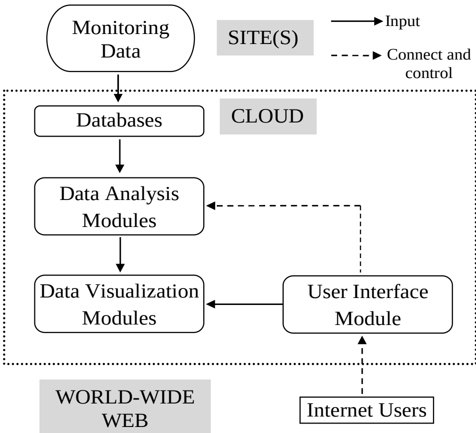


Fig.1 Framework of proposed cloud-based data visualization system

Estimation of FRTF The FRTF enables the exploration of the relationships between the dynamic behaviour of different components, in both lateral and vertical directions making use of recorded acceleration responses. FRTF (Trethewey and Cafeo 1992), therefore is employed for analysis of the dynamic interactions between axlebox and frame and also between axlebox and carriage body.

3.2 Development of software modules for data analysis and visualization

The core modules of the cloud-based data visualization and analysis system are supported by establishing several software modules:

(1) A networking system to transmit data from remote sites to the cloud;

(2) A cloud-based database that allows data updating and management of the monitored data;

(3) A visualization module embedding data processing algorithms and train drawing commands. In addition, the preferable data sampling rates is defined to balance the efficiency and accuracy of the data processing. The realization solutions of the modules through a cloud platform are shown below.

To realize the condition monitoring tasks on cloud system, the visualization module in the system implements a front-end web service. The system consists of (1) a PAD that operates the system and visualizes the data, (2) a web server that performs the model calculation and provides web service, and (3) a cloud-based database that stores the data.

In all the modules for the system, it is crucial to design a feasible web server. The web server is built by PHP (5.6.30) using NGINX (1.11.9). NGINX is a light-weight HTTP server and reverse proxy. A client program is installed on the PAD visualizing the data according to user’s input. The Graphic User Interface of the client program is developed by Java Script and PHP. The client requests the data from the web service through the NGINX-PHP engine (PHP-FPM). The preferable data sampling rate is defined to balance the efficiency and accuracy of the data processing.

In addition, we separate the data storage because there are large chunks of data. The data is stored by MySQL in a data server connected by the web service. Data can be dynamically operated in the data store without affecting the logic of the web service or the PAD client. To intuitively show the property of the data, the system also integrates a video showing the movement of the train when the data was collected. The video was uploaded to YouTube and synchronized by the PDA client using YouTube API.

This aforementioned design provides a feasible solution for establishing a cloud-based system for condition monitoring using acceleration data. This design is then realized, verified and demonstrated using the in-service monitoring accelerations of a train running on a high-speed railway in China.

4. APPLICATION TO MEASURED ACCELERATION TIME-HISTORY OF IN-SERVICE HIGH-SPEED TRAIN

4.1 Collection of in-service monitoring data

An in-service train running on a China high-speed railway was instrumented with sensors to monitor the variations in acceleration, strain, noise and temperature for different structural components. The monitoring work was conducted for a total of one month between December 2015 and January 2016. During the monitoring period, the train ran at its normal operating speed between stations, at 160-200 km/h.

The monitored high-speed trains comprised 8 carriages, 4 powered and 4 trailer carriages. To understand the dynamic characteristics of an in-service high-speed train bogie and carriage body, accelerometers were installed at 12 locations in the directions of vibration transmission, including axleboxes, bogie frames, sub-components connecting to the axlebox and the floor of the carriage body. The 12 locations were based on a theoretical analysis of the vibration transmission path directions from wheel to carriage body. As shown in Figure 2(a), 11 triaxial electronic accelerometers and 1 triaxial Fiber Bragg grating (FBG) accelerometer were respectively deployed on the trailer carriage body floor, the powered and and trailer carriage bogies (axleboxes, frames and sub-components) to measure accelerations in longitudinal, vertical and lateral directions. A sampling rate of 5000 Hz was set for the monitoring of acceleration data. The 12 accelerometers recorded simultaneously during monitoring.

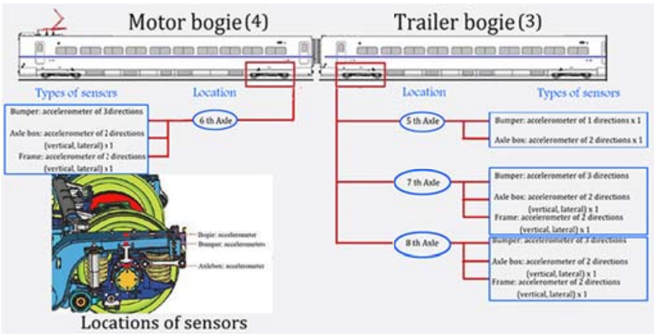
Once installed, the accelerometer cables were attached to the surface of the bogie and vehicle, passed through the front trailer carriage door and connected to the data acquisition systems. These systems were placed inside a trailer carriages, under the first row of passenger seats, a place always connected to electricity enabling continuous operation and data collection. Figs. 2 (b) and (c) show the detailed locations and measured acceleration directions of the accelerometers installed at the carriages and bogies.

One month of data from all 12 accelerometers was collected from the data acquisition systems. The accelerations of at the trailer bogie, namely, those at axlebox, frame and carriage body at different axles were selected for the analysis using FRTF to investigate vibration transmission between train components.

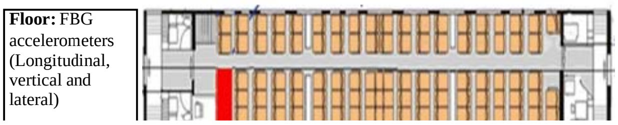
The next task is to establish the proposed cloud-based data visualization system of the monitoring accelerations. In the following, the performance of the system is verified through samples of 30 seconds of the monitoring accelerations histories simultaneously recorded from all 12 accelerometers of 12 locations. These data are imported into the system.

4.2 Results

One of the two data analysis tasks in current study for condition monitoring is to analyze the accelerations in both time and frequency domains; the other task is to understand the dynamic interactions between different train components through deriving FRTF results by analyzing accelerations. According to this need, the cloud-based data visualization system is developed as shown in Fig.3. A full version of the system is shown at http://dashboard.jimyun.com/chart/index.php. The system receives the 30 seconds' monitoring accelerations of all accelerations and video data, and then stores the data in a cloud-based data server by MySQL. This data can be accessed and selected by the users on the interface of the system. As can be seen in Fig.3 (a), users of the system can select the accelerations of different locations for further analysis purpose. In addition, system interface also displays the corresponding video data of the monitoring period and the layout of the accelerations deployment, as shown in Fig.3 (b).



(a)



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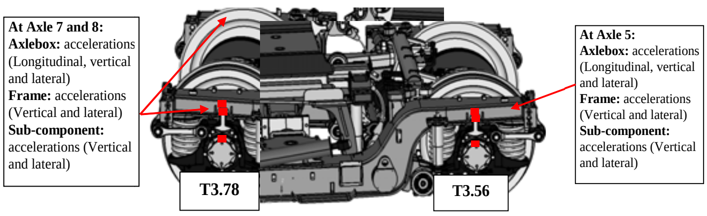
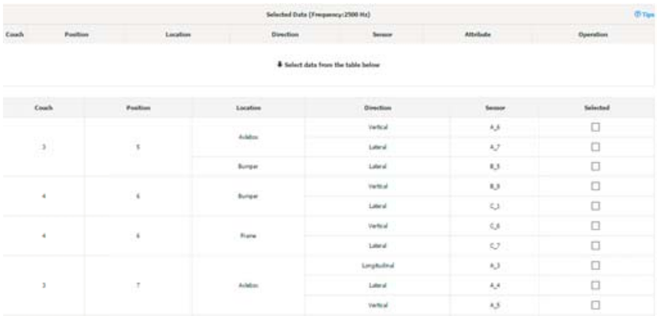
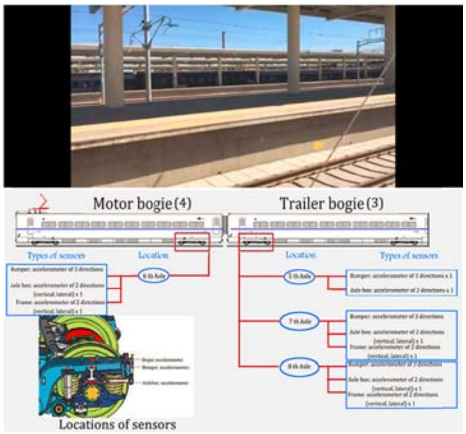


(c)

Fig.2 Layout of accelerometers deployment: (a) Deployment of sensors on high-speed train; (b) Floor of carbody of trailer car; (c) Bogie of trailer car (on frame, axleboxes and subcomponents)



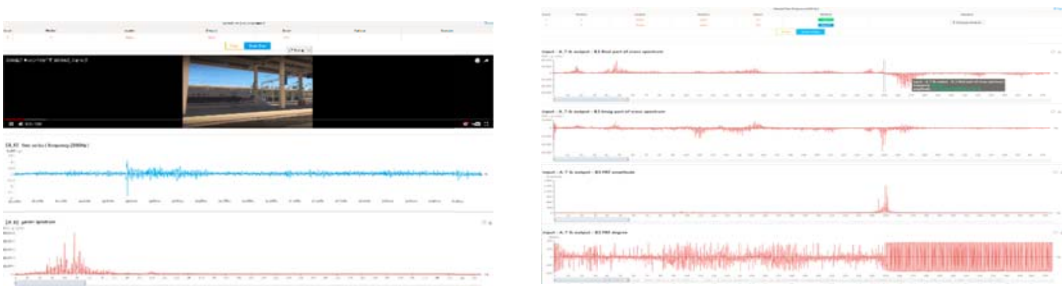
(a)



(b)

Fig.3 Interface of established system: (a) Selection of accelerations of different locations; (b) Demonstration of video data and layout of acceleration deployment

The analysis function of the established system to the accelerations are developed. It can be seen from Fig.4 (a) that the time and frequency domains information of the acceleration of an accelerometer are demonstrated together with video data of the monitoring period. As also shown in Fig.4 (b), the FRTF of the accelerations of two accelerometers are shown. The FRTF results provide information relating to “Real and imaginary parts” of the cross spectrum, and “amplitude and degree” of the FRTF.



(a) (b)

Fig.4 Analysis of monitoring data: (a) In-service monitoring acceleration data and PSD of a sensor; (b) FRTF of accelerations of sensors as input and output signals

To develop an efficient online data visualization system, it is crucial to reduce data processing time for rapid reveal of analysis outcome. One feasible solution to increase the efficiency is to reduce the sampling rate of the input data at a descend level which does not influence the effectiveness of the system (e.g. target outcome can still be obtained). Fig. 5 shows an investigation result about the time consumptions of operation FRTF for different sampling rates of input data. It can be seen that the increase of sampling rate raises time consumption to finish data processing: the time consumption for 1000 Hz input data is only 1.6 seconds, whereas for 5000 Hz reaches18.6 seconds. The increase trend in processing time from 1000 to 2500 Hz is relative slow, whereas there is a sharp increase in processing time between the sampling rates of 2500 and 5000 Hz.

In view of the above findings, the sampling rate is set as 2500 Hz with processing time at 2.6 seconds. The benefits of this setting is to ensure FRTF results obtaining from the input data at 2500 Hz to be effective, while keeping the processing time being still in a satisfied level (e.g. within 3 seconds).

After establishing the system, internet users can have access to the data visualization system through laptop, PAD or mobile devices. Fig.6 shows the system operating well on PAD and mobile devices.

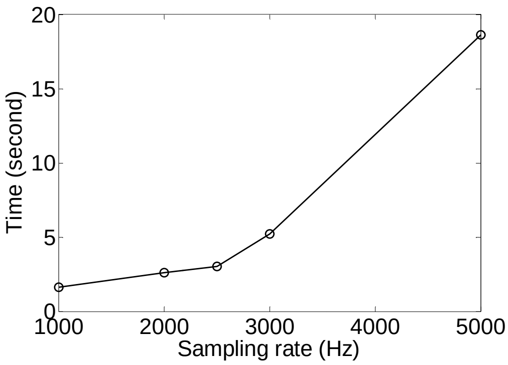


Fig.5 Processing time versus sampling rate of input data

(a) (b)

Fig.6 Use of different devices to connect with cloud-based data visualization system: (a) PAD platform; (b) Mobile device

5. CONCLUSIONS

In this paper, a cloud-based data visualization system is developed for the purpose of condition monitoring of in-service high-speed train. The system is able to realize the functions include: (1) Updating in-service monitoring data from different monitoring sites; (2) Analysing and visualizing the accelerations of the accelerometers of train components using FFT, FRTF or other applicable algorithms towards condition monitoring; (3) Providing world-wide accessible channel to connect, analyse and download the condition monitoring results. The performance of the system is verified using the in-service monitoring accelerations obtained from the instrumented train running on a high-speed railway in China. The results show the feasibility of using the cloud-based system for condition monitoring. It is found a high sampling rate to demonstrate the monitoring data will lower the speed in processing the FRTF results. Therefore, it is more appropriate to set a lower sampling rate for effective data processing on the cloud-based system.

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