Construction of Online Monitoring System for Track Safety and its Vibration and Noise

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ABSTRACT
In accordance with the requirements of intelligent and scientific maintenance and repair for rail transit, the on-line monitoring and intelligent assessment technologies for infrastructure safety as well as vibration and noise indexes are studied. In connection with the line status of the Shanghai rail transit network, typical line sections are selected to lay out the online status monitoring equipment so as to track health and safety indexes of rails and real-time noise and vibration levels. By means of online real-time data collection and synchronous analysis technology, the Shanghai rail transit online monitoring system for track safety status and its vibration and noise takes shape, thereby achieving real-time monitoring for on-site vibration and noise as well as safety status, and providing assistant decision-making reports in connection with relevant index systems and in accordance with relevant time periods.

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1 Background
While the urban rail transit serves passengers and facilitates their trips, the equipment and facilities in operation are also facing the pressure of complex environmental conditions and increasing maintenance workloads. Shanghai Metro actively responds to the requirements of the Outline for Building a Strong Country of Transportation\(^1\) and the Shanghai Municipal Thirteenth Five-Year Plan for Promoting the Construction of Smart Cities. At present, the three major sectors of construction, operation and maintenance have started the construction of intelligent metro. The specialty of public works is an important part of the Shanghai Metro operation and maintenance system.

The refined and intelligent operation and maintenance of infrastructure and the construction of intelligent public works are imperative. These are the important parts of the current construction of Shanghai intelligent metro. The informatization and intelligentization applications in urban rail transit should take demand as the fundamental, and give first priority to simplicity.\(^2\)

Among them, intelligent and scientific pre-alarming for line and track structure maintenance is particularly in great need. Vibration and noise data are closely related to track logs, line conditions, operation conditions, rail conditions and rail damage data. In order to understand their conditions and their long-term variation trends, multi-dimensional data must be accumulated and correlated in connection with periodic detection and intelligent monitoring systems before the deduction for vibration and noise data related to tracks and the prediction regarding the maintenance and repair of track structures are finally implemented.

At the same time, passengers and residents living alongside metro lines have increasingly higher requirements for riding comfort and living environment. While urban rail transit brings convenience to people's trips, it also brings about environmental vibration and noise problems. This
issue has gradually become a crucial one in environmental impact assessments. Under the premise of ensuring safety and reliability, intelligent means and intelligent analyses must be used to form reliable and quantitative correlation and integration based on track structure conditions and vibration and noise levels, thereby effectuating differentiated predictions, operation and maintenance related to vibration and noise levels under different line conditions, and improving the quality of riding for passengers as well as the quality of living environments alongside metro lines.

2 Construction Objective and Main Contents

In accordance with the intelligent and scientific pre-alarming requirements for line maintenance, Technical Center of Shanghai Shentong Metro Group Co., Ltd. (hereinafter referred to as Technical Center) makes research on the online technical means for monitoring vibration, noise and safety indexes, selects typical line sections and cross sections to deploy online-status monitoring equipment, and studies the technologies for implementing real-time collection of track health and safety indexes together with vibration and noise data as well as for implementing preliminary analyses thereof; makes research on real-time data transmission, processing and analysis, storage and reading technologies, effectuates real-time monitoring for on-site vibration, noise and safety indexes, and effectuates pre-alarming functions when exceeding relevant limits in conjunction with index system construction; and forms the Shanghai rail transit online monitoring system for track safety status and its vibration and noise (hereinafter referred to as the online monitoring system for track safety and its vibration and noise) by combining data collection and analyses with tracking of status indexes.

The system tracks the key line sections with potential track safety hazards, dynamically monitors the vibration and noise indexes at sensitive line sections, displays on-site information via multi-dimensional real-time data, and effectuates reminding, pre-alarming and other functions in connection with big data analyses. The system platform adopts a distributed monitoring system and implements effective real-time monitoring for track and line statuses according to the requirements for monitoring track safety and its vibration and noise. The monitored physical quantities include the vertical and horizontal displacements of the trackbed slab, the transmission force of the vibration isolator spring, the temperature and strain of the steel track, and the vibration of the bridge deck and the trackbed slab as well as the noise of the bridge deck. The data monitoring can provide support for the decision-making regarding technical solutions, and effectuate pre-alarming related to safety and environment protection.

3 Overview of the Monitoring System

3.1 Overall system requirements

The monitoring system should be built within the relevant standard and specification system and within the network information security system. In designing and constructing this system, it is necessary to consider the rail transit site environment comprehensively, and ensure the long, safe and stable operation thereof after its deployment. The data collecting terminals can obtain various information needed for track-condition monitoring. They are connected with a variety of sensors and are very easily-extensible so as to reserve rooms for functions to be added at later stages. The equipment of this monitoring system should be easily deployed and maintained, and has relatively high cost performance.

3.2 Systems architecture

This system is composed of the following five layers: the intelligent perception layer, network layer, data layer, application layer and display layer. The intelligent perception layer is composed of data collection terminals distributed alongside metro lines, responsible for sensor’s power supply, signal collection and processing, access to the Internet and data transmission back to the server. At the same time, this layer is enclosed by cabinets with certain degrees of protection, which are selected in accordance with the on-site use environment, and it is equipped with external power supply and signal interfaces. The front-end intelligent perception items include video, trackbed slab displacement, spring force of vibration isolator, rail temperature, rail strain, vibration of bridge deck and trackbed slab, and noise of bridge deck. After the data collection terminal has obtained the data from sensors, it is necessary to implement data calculations and processing locally, such as triggering judgment, wave filtering, characteristics value extraction, file storage, network communication, etc. In this way, useful information can be made available quickly, thereby reducing the burden of both the network transmission and the central processing unit.

The initial construction of the network layer has realized two ways of communication: Internet and mobile communication network. Figure 1 is the schematic of the architecture consisting of the perception layer, network layer and data layer.
The core of the data layer construction is the database system, which is composed of the following 4 databases for master data, basic information data, video data and metadata, respectively. The above-mentioned master data are the signal data that reflect track safety as well as vibration and noise indexes thereof as perceived intelligently on-site. Figure 2 is the file view page for the master database. The basic information data include geological parameters of soil, line and track conditions, vehicle operation information, etc. The video data are mainly the video information of the monitored cross section. The metadata are the data that describe information resources or data objects, thereby effectuating the search, calling and effective management for the information in various databases.

The application layer includes the data analysis platform and intelligent reporting system. The application layer of the online monitoring system for track safety and its vibration and noise analyzes the monitored data of vibration, noise, displacement, and stress, and provides assistant decision-making analysis reports in connection with relevant index systems and relevant time stages.
The content of the display layer includes large-screen display systems and handheld intelligent terminals. The information displayed on large screens includes: rail status and rail damage data information; onsite monitored information regarding track safety and vibration and noise; data statistics information, etc. Handheld intelligent terminals can service the online tests, maintenance tour-inspection for track safety and its vibration and noise.

4 Demonstration Application

At present, the online monitoring technology is applied to several selected cross sections at certain elevated and underground mainline sections of Shanghai Metro to implement the real-time monitoring for the safety and environmental indexes regarding track statuses. Figure 3 and Figure 4 refer to the monitored cross sections of the elevated and underground line sections, respectively.

The collector collects the data onsite and has independent operation and processing capabilities; it supports data collection, data processing, file recording, network transmission and other functions. According to the online calculation and signal processing algorithms, the collector transmits the calculated characteristic quantities back to the master server. The collector can record the real-time data of a specified time period locally as required. The collected data is connected to the Internet through fixed networks or 4G networks, and the data are sent back to the server. The server receives data from several data collectors, records them in the database, and provides functions such as query, export, alarm, and visualization. Figure 5 and Figure 6 show the sensor layouts at the monitored cross sections.

Figure 3. Monitored Cross Section of Elevated Line.

Figure 4. Monitored Cross Section of Underground Line.

Figure 5. Schematic diagram of layout of force sensor of vibration isolator.
5 Achievements and Prospects

Technical Center independently develops and deploys the online monitoring system for track safety and its vibration and noise; it applies the online monitoring technology to a number of cross sections at certain elevated and underground mainline sections of Shanghai Metro, thereby implementing real-time monitoring for the safety and environmental indexes regarding track statuses. The the online monitoring system for track safety and its vibration and noise features a stable operation. Since it was launched online on Oct. 1, 2019, this system has recorded more than 180,000 safety and environmental indexes regarding track statuses when trains passed the relevant cross sections. The analytical results of the monitored data can provide support for the decision-making regarding maintenance and repair of track structure as well as technical solutions of vibration and noise reduction, and also provides pre-alerts regarding safety and environment protection.

In the future, the project team will continue to correlate vibration and noise data with track logs, line conditions, operating conditions, and rail status and damage data thereby forming correlation analyses between vibration & noise data and track structure status & damage data; in connection with the track structure status data as well as other data correlated with vibration and noise, they will also evaluate the statuses of track structures and track components under different vibration and noise conditions, and implement the deductions regarding vibration and noise data related to track structures as well as the predictions regarding maintenance and repair.

References

The Outline for Building a Strong Country of Transportation by the CPC central committee and the state council [EB/OL], 2019-09-19.
