Application of the Virtual Reality Technology in Structural Safety Monitoring of Shield Tunnels

Xinteng Ma 1, Yingchun Liu 2, Junwei Wang 2, Dan Wang 2, Yang Liu 1

1 School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin, 150090, China
2 Railway Group 5 Mechanization of Engineering Limited Liability Company, Hengyang, 421002, China
ly7628@hit.edu.cn

Abstract. Many structural health monitoring (SHM) systems of actual tunnels are underused, with abstract data, chaotic information and the diagnostic results beyond comprehension. It is necessary to establish the visual connection between the visualization of monitoring network and massive structural information of tunnels. To address this issue, this study proposed a structural visualization method based on the panoramic virtual reality technology, combining the panoramic spherical image and the real-time monitoring data of tunnel obtained from SHM system. First, a software system for structural safety monitoring of an actual shield tunnel was developed on the basis of the combination of the panoramic visual technology and B/S (Browser/Server) architecture system. Second, the panoramic modelling method for specific tunnel structure environment was discussed in detail, and then the mechanism of data transmission and information access in panoramic virtual reality environment was investigated deeply. Finally, in view of the demands of practical application, the function modules of the abovementioned software system were described. Some key issues of how to develop each software module using the panoramic virtual reality technique were analysed e.g., online geographic information and cloud platform management. The results show that the panoramic virtual reality technology completely meets the needs of real-time processing, information management, virtual roaming and maintenance management in tunnel structural safety monitoring.

1. Introduction

Structural health monitoring (SHM) [1-3] continuously and reliably acquires the response of structures and the loads acting on structures, identify structural and design defects during construction and diagnose the damage of structures during operation; thus, this technique has been extensively applied to actual tunnels. Amounts of data are accumulated as SHM systems operates continuously, and most of these data are abstract and complicated to be understand clearly. Therefore, it is necessary to establish the visual connection between the visualization of monitoring network and massive structural information of tunnels.

Data visualization has been investigated by some researchers [4, 5] using different approaches and measurements such as 3-D laser scanning, video-based technique and building information model (BIM) technique, etc. However, the common issue of these technology lies in the heavy burden of calculation and the requirement of high performance of computer hardware. Comparing with the abovementioned
technique, the virtual reality technique is more efficient to achieve the 3-D visualization of large-scale structures such as tunnels without the special requirement of computer hardware. Furthermore, the visualization of the operating condition of tunnels could be shown with mobile electronic instruments, e.g., cellphone and laptop. On the basis of this point, this study proposed a structural visualization method based on the panoramic virtual reality technology, combining the panoramic spherical image and the real-time monitoring data of tunnel obtained from SHM system.

2. Implement of the virtual reality technique in the field of structural health monitoring

Using the panoramic spherical image, 3-D virtual reality technique reappears the scenes of tunnel based on computer vision; thus, the user could fully feel the immersion of actual tunnel. The 720° panoramic image is obtained using the combination of camera and panoramic disk, and then the fisheye lens is applied to stitch the photos from different visual angle. The flow chart of generating the panoramic image is shown in figure 1, and the results of stitched photo with 720° panoramic scene of the inner of one metro shield tunnel is shown in figure 2. After stitching all the photos, the software Krpano is implemented to transform the stitched image to panoramic navigation. If the generated Lrpano viewer is embedded into the HTML webpage, the panoramic navigation under the webpage environment is achieved.

One of the popular frameworks of software of SHM of shield tunnel is B/S framework including the data layer, the business logic layer, the displacement and interaction layer. All the data obtained from SHM system of shield tunnel consist of the data layer. All the diagnosis algorithms of the structural safety of shield tunnel generated the main contents of the business logic layer. For the last layer, the user could obtain, learn and share all the information of the condition of shield tunnel by browsing the webpage.

During the panoramic navigation, all the feedback of user is signed with different hotspot. All the static information, e.g., picture, text message and audio, are recalled and defined through xml file. All the dynamic information are recalled by using JavaScript file, and then all the algorithms of evaluating the condition of shield tunnel are operated through JSP file; then the results are sent back to the logic layer, and the final results are described in the displacement and interaction layer. The framework of software system of SHM based on the 3-D virtual reality technique is shown in figure 3.

3. Application in actual shield tunnel

In this section, the virtual reality technique is utilized to establish the software of SHM of an actual metro tunnel. With the B/S framework, the general software interface of SHM of this tunnel is shown in figure 4.
Figure 3. Framework of software system of SHM based on the 3-D virtual reality technique

Figure 4. Software interface of SHM of an actual metro tunnel
The generated software system can be visited by user who can access the local area network. The user can check and manage all the structural response of shield tunnel under the virtual reality environment. The function is shown in the left upper picture of figure 5. Meanwhile, the design and management information of the SHM system can also be visited under the panoramic virtual reality environment, as shown in the right upper picture of figure 5. The geographic information of metro tunnel also are inquired with the interaction between the reality environment and the user’s feeling, and this is found in the left bottom picture of figure 5. Besides the abovementioned functions, all the information related with the regular maintaining and inspection of shield tunnel can be input into the database of the software system, as shown in the right bottom picture of figure 5.

![Figure 5. Detailed software interface with different function](image)

4. Conclusions
A structural visualization method based on the panoramic virtual reality technology is presented in this study, and this technique is applied to the SHM of an actual shield tunnel. This technology can realize the real-time monitoring data transmission and facilitate the effective management of structural safety of shield tunnel. Under the 3-D panoramic virtual reality environment, the users are easy to operate, roaming and access to information obtained from the complicated SHM system. The application results show that the software system based on the proposed technology has good performance and superior experience in real-time monitoring, information management, virtual tour and operation and maintenance management.

Acknowledgment(s)
This study is supported by the Key Research & Development Program of Shandong Province of China (Grant No: 2019JZZY010427).

References
[1] J. P. Ou, H. Li, “Structural health monitoring in mainland China: review and future trends,”
Structural Health Monitoring, vol. 9(3), pp. 219-231, 2010.

[2] V. G. M. Annamdas, S. Bhalla, C. K. Soh, “Applications of structural health monitoring technology in Asia,” Structural Health Monitoring, vol. 16(3), pp. 324-346, 2017.

[3] M. Vagnoli, R. Remenyte-Prescott, J. Andrews, “Railway bridge structural health monitoring and fault detection: State-of-the-art methods and future challenges,” Structural Health Monitoring, vol. 17(4), pp. 971-1007, 2018.

[4] F. Boshce, C. Haas, B. Akinci, “Automated recognition project 3D status visualization and performance control,” Journal of Computing in Civil Engineering, vol. 31, pp. 311-318, 2009.

[5] L. Brilakis, M. Lourakis, R. Sacks, S. Savarese, S. Christodoulou, J. Teizer, A. Mahmalbaf, “Towards automated generation of parametric BIMs based on hybrid video and laser scanning data,” Advanced Engineering Informatics, vol. 24, pp. 456-465, 2010.

[6] N. Rebecca, B. Anna, G. Branko, “Virtual environments for visualizing structural health monitoring sensor networks, data, and metadata,” Sensors, vol. 18, pp. 243-256, 2018.