Application of 3D Laser Scanning Technology for Shield Tunnel Inspection

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Abstract. This paper describes the application of 3D laser scanning technology in shield tunnel inspection from the working mechanism. The point cloud data collection process, processing method and result analysis of the technology in shield tunnel inspection are introduced. Finally, combined with point cloud data obtained for dislocation and clearance inspection. The dislocation and clearance inspection are visually shown by the three-dimensional cloud chart. It shows that reliable inspection information can be obtained by using this technology, and has certain practical value for tunnel inspection.

1. Introduction

Tunnel inspection is an important task to ensure the safety of tunnel construction and operation. The current tunnel inspection is mostly limited to extracting and analyzing 2D cross-sections. The traditional method takes time and effort and occupies the line, most of them use static measuring instruments to inspect the internal structure, and it is difficult to grasp the actual tunnel deformation. In recent years, 3D laser scanning technology is developing rapidly in spatial information acquisition. Applying 3D laser scanning technology to tunnel safety inspection is a research hotspot. Compared to traditional tunnel inspection methods. The 3D laser scanning achieves an advance from a single section and adopts multi-point cross-section scanning to analyze the whole tunnel.

Domestic and foreign scholars have done a lot of research on the application of 3D laser technology in tunnel engineering. Yoon Jong-Suk[1] proposes to use mobile 3D laser scanning to acquire 3D data of railway tunnels; Delaloye D[2] gives the recommended values for 3D laser scanning parameters to obtain high quality point cloud data; Han Jen-Yu Y[3] uses two-dimensional modeling method to extract the contour of the tunnel cross-section point cloud for deformation analysis; Wang Lingwen[4] divides the 3D laser scanning tunnel point cloud data into slices, uses the multi-point coordinate adjustment method to obtain the slice center and radius, compares the fitted ring and the design contour to determine the convergence deformation of the tunnel; Li Zongping[5] studied the key issues of three-dimensional laser technology applied in tunnel deformation monitoring, section intrusion limit and secondary lining thickness inspection project. This paper will enable the application of 3D laser scanning technology in shield tunnel clearance detection and staggered.
2. 3D laser scanning technology.

2.1. 3D laser technology scanning mechanism
The 3D laser scanner returns to the surface of the object to be measured by emitting laser light and returns to the original path. Calculate the time it takes for the beam to be transmitted from being received. Then calculate the distance S from the instrument to the point to be measured. When measuring the distance value, the horizontal and vertical angles are recorded simultaneously. From the distance measurement S, the horizontal angle α and the vertical angle θ, the relative three-dimensional coordinates of the point P (X Y Z) are solved, as shown in figure 1. Then you can find the three-dimensional coordinates of the measured points at each moment. These points are arranged according to their respective spatial coordinate positions. A spatial data point cloud that forms the target. The point cloud reveals the shape and target space structure of the target.

2.2. Station spacing
When using 3D laser scanning technology in the tunnel, the incident angle of the 3D laser is an important factor affecting the accuracy of the scanning data on the tunnel. The incident angle is inversely proportional to the accuracy. In practical applications, in order to reduce the number of scans, the station spacing is usually increased, so that the incident angle of the laser increases and the accuracy decreases. It is therefore important to determine a reasonable maximum station spacing. The relationship between station spacing, tunnel inner diameter and incident angle is shown in figure 2.

If the test station is on the central axis of the tunnel, the maximum point of the maximum angle of incidence angle B, Can get this formula:

\[ \theta_{\text{max}} = \arctan \left( \frac{S}{D} \right) \]  

where \( \theta_{\text{max}} \) is the maximum angle of incidence of the station scanning range; S is the station spacing; D is the inner diameter of the tunnel.

Figure 2. The relationship between station spacing, tunnel inner diameter and incident angle.

D. Delaloye [6] recommends taking S=1D, but the test by D.D. Lichit [7] starts to rise sharply when the incident angle is greater than 65°. It can be seen from the formula that when \( \theta_{\text{max}}=65° \), S= 2.1D. Considering the conditional limitations measured at the tunnel site, the station may not be able to be placed on the central axis of the tunnel. Xie Xiongyao [8] recommends S= (1~2) D, and this paper uses S=2D
2.3. Stitching method
Integrate the data of different stations into a whole, and obtain the point cloud of the whole tunnel. This process is called splicing of point clouds. The essence of splicing is the transformation of the point cloud coordinate system. Unify point clouds of different reference coordinate systems into one coordinate system.

This paper adopts the double-station splicing scheme based on the target ball. The stations are linked by the target, and the splicing principle is shown in the figure 3. In the direction of detection, one station is set at a distance of 2 times the tunnel diameter, and three targets are set in the middle of the station.

3. Measured application
3.1. Technical route
The 3D laser scanning measurement technology route mainly includes the scheme design, field data acquisition, internal data processing and output of the results, as shown in Figure 4.

This paper selects the Baicheng shield tunnel as the study area, and the point cloud data registration and filtering are completed based on Faro Scene. The inspection of tunnel quality in this paper includes two aspects of dislocation and clearance inspection. Data acquisition using Faro Focus S70 3D laser scanner. The scanner has a built-in 165 million pixels, a scanning range of 360°X300°, a scanning speed of 976,000 points/second, and a ranging error of no more than ±1mm within 25m. Scan parameter setting, resolution set to 1/5 resolution, 2X quality. The scan time of one station is approximately 3 minutes. The point cloud scanned by the scanner is shown in figure 5.

3.2. Results and analysis
The processing software is a PCAS software developed by Chengdu Tianyou Intelligent Tunnel to carry out the design data and the actual measurement scan data. New construction projects and import design parameters such as flat curve, vertical curve, and design section, as shown in figure 6. The red dot
indicates the position of the station in the line. You can visually see where the station is located throughout the line.

3.2.1. Dislocation
The dislocation refers to the phenomenon that the two ring pieces are relatively displaced when the two ring pieces are adjacent to each other in the tunnel. The dislocation between the ring segments is mainly caused by an uneven external force. When the concentrated load received at a certain point exceeds the design limit value, the tunnel is biased, resulting in relative displacement between the segments. In the software, it can be intuitively observed that the arc surface between the adjacent segments is not flat in the figure 7, the difference between the segments at DK207+121.89 is about 1.4cm.

3.2.2. Clearance inspection
According to the tunnel safety monitoring requirements and the actual situation of the project, the value of the cross-section is represented by the color assignment of the vertex. Three-dimensional display of Baicheng Tunnel DK206+380~DK206+420. In the tunnel section detection, the deviation is 0.1m as the critical threshold, and the critical threshold is exceeded in red; 0.05m as the warning threshold, displayed in yellow; The warning threshold is displayed in blue. As shown in the figure 8: the difference is in the safe range.
Figure 8. Clearance inspection three-dimensional display.

By comparing the point cloud data of the same section with the design section, it is possible to analyze whether the shield section fits the design section. The red outline is the design section, and the blue outline is the measured tunnel section of the 3D laser scanning. The section extraction can set the measurement results and deviation of the section of the arbitrary interval mileage extraction, as shown in figure 9.

Figure 9. Clearance inspection report.

It can be seen from the graph data that the maximum overrun is 0.061m and the linear average overrun is 0.042m at DK206+380. At DK206+426, the maximum overrun is 0.051m and the linear average is over 0.028m. Data from 3D laser scanning of DK206+380-DK206+410, Select a section to generate a report every 1m, Draw a section inspection-mileage map to see the overall situation of the tunnel, as shown in figure 10.
4. Conclusion
The paper describes the basic flow and method of tunnel inspection using 3D laser scanner. The tunnel section is extracted from point cloud by the commercial software PCAS, and compared with the theoretical section. The clearance inspection of the tunnel is carried out; This paper analyzes the dislocation in the commercial software SCENE. The dislocation and clearance inspection are visually shown by the three-dimensional cloud chart. With the increasing emphasis on tunnel construction, safety maintenance and quality in China, 3D laser scanning technology will become a new important technical means to ensure tunnel operation, safety maintenance, and quality.

References
[1] Yoon Jong-Suk, Sagong Myung, Lee J S. (2009) Feature extraction of a concrete tunnel liner from 3D laser scanning data. J. NDT&E International, 42(2): 97-105.
[2] Delaloye D. (2012) Development of a new methodology for measuring deformation in tunnels and shafts with terrestrial laser scanning (LIDAR) using elliptical fitting algorithms. D. Kingston: Queen’s University.
[3] Han Jen-Yu, Guo Jenny, JIANG Yi-Syuan. (2013) Monitoring tunnel profile by means of multi-epoch dispersed 3D LIDAR point clouds. J. Tunnelling and Underground Space Technology, 33(1): 186-192.
[4] L.W.Wang, X.Y.Cheng, C.H.Wang. (2013) Study of the 3D laser scanning technology for tunnel inspection. J. Geotechnical Investigation & Surveying, 53-57.
[5] Z.P.li, Y.T.Zhang, Z Yang. (2017) Application of 3D Laser Scanning Technology to Tunnel Deformation Monitoring and Cross-section Detection. J. Tunnel Construction, 37(3): 336-341.
[6] LICHTI D D. (2007) Error modelling, calibration and analysis of an AM–CW terrestrial laser scanner system. J. ISPRS Journal of Photogrammetry and Remote Sensing, 61(5): 307–324.
[7] Y.X.Xie, X.Z.Lu, H.Y.Tian, Q.Q.Ji, P.Li. (2016) Development of a modeling method for monitoring tunnel deformation based on terrestrial 3D laser scanner system. J. Bulletin of Surveying and Mapping, (02): 143-144.
[8] Y.X.Xie, X.Z.Lu, H.Y.Tian, Q.Q.Ji, P.Li. (2013) Development of a modeling method for monitoring tunnel deformation based on terrestrial 3D laser scanning. J. Chinese Journal of Rock Mechanics and Engineering, 32(11): 2214-2224.