ISSN: 2414-1895 DOI: 10.6919/ICJE.202407_10(7).0019

Design and Implementation of Tunnel Construction Volume Analysis and Management System based on Point Cloud

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Abstract

Accurately mastering the data information of the tunnel construction contour surface is the key difficulty in controlling the over-excavation and over-consumption of tunnel construction. This article developed a set of tunnel construction volume analysis management system based on point cloud, which realized the three-dimensional precise measurement of tunnel construction contour surface, automatic analysis and processing of data, visualization of construction volume data, etc. It combined the field work of three-dimensional measurement of tunnel construction contour surface with the automatic analysis of measurement data, realizing on-site real-time scanning, real-time analysis and on-site guidance for construction. It automatically analyzed and calculated the quantities of over-excavation and over-consumption projects and uploaded them to the management terminal. Management and operation personnel can instantly grasp accurate information about tunnel construction, formulate countermeasures in a timely manner, control tunnel construction over-excavation and over-consumption, and prevent lining disengagement.

Keywords

3D Point Cloud; Tunnel Construction; Engineering Volume; Software System.

1. Introduction

With the construction of modernization, tunnel engineering is flourishing in China. The geological conditions of tunnels are harsh, the construction environment is complex, and there are many inconveniences in construction management and control, resulting in over excavation and over consumption during the construction process becoming the most important factors affecting tunnel construction costs. Therefore, effective control of tunnel construction over excavation and over consumption, and timely and accurate grasp of tunnel construction contour data information have become the key to solving the problem [1]. At present, the main method for obtaining tunnel construction profile is through cross-sectional measurement, and the main instruments used are cross-sectional instruments and total stations. These methods are inefficient and require a lot of time and manpower [2-6]. Compared to traditional measurement methods, 3D laser scanning technology provides a faster, safer, and more effective method for investigation, measurement, and monitoring. 3D laser scanners can work in extremely complex spatial scenes. By finely scanning the space, a large amount of 3D laser point cloud data is collected and stored in a computer. Then, software is used to quickly construct 3D models of various non-standard and irregular large entities [7-10]. Therefore, starting from the key issue of accurately grasping the data information of tunnel construction profile, this article has developed a point cloud based tunnel construction volume analysis and management system, established an algorithm system and management application process for three-dimensional precision measurement, automatic data analysis and processing, and data application of tunnel

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construction profile. The external work of three-dimensional measurement of tunnel construction profile is combined with the internal work of automatic analysis of measurement data, achieving on-site real-time scanning, real-time analysis, and on-site guidance of construction. The system automatically analyzes and calculates the number of over excavation and over consumption projects and uploads them to the management end. Management and operation personnel immediately grasp the accurate information of tunnel construction, formulate response measures in a timely manner, control tunnel construction over excavation and over consumption, and prevent lining void.

2. System Design

2.1 System Logic Structure

The logical structure of the tunnel construction volume analysis and management system based on point cloud is mainly divided into three parts: 3D point cloud data processing software for tunnel contour surface, tunnel construction volume analysis statistics and visualization platform, and mobile application for tunnel construction volume data management, as shown in Figure 1.

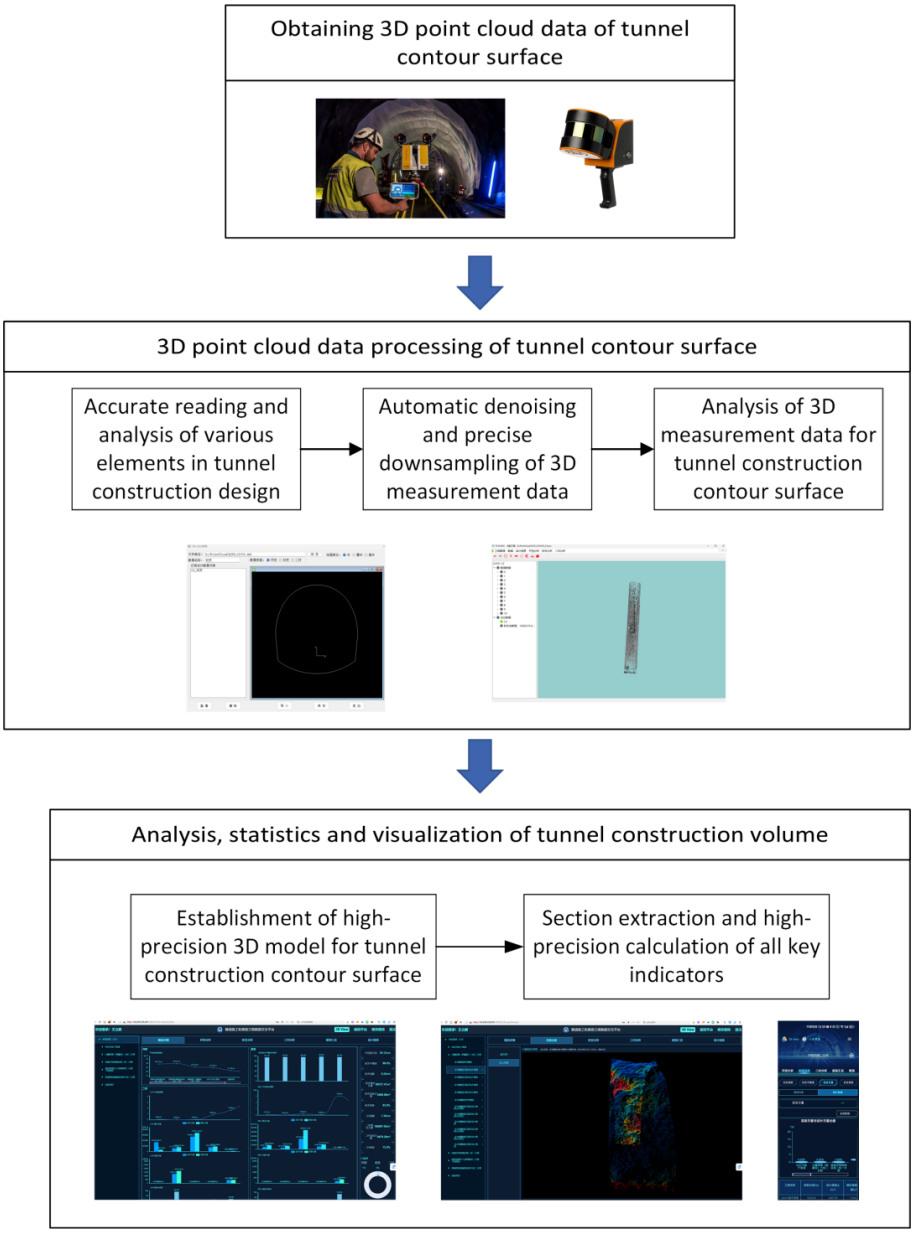

Figure 1. System Logic Structure

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The 3D point cloud data processing software for tunnel profile surface runs on the construction site computer, which is used to process the obtained point cloud data in a timely manner. It mainly realizes the accurate reading and analysis of various design elements in tunnel construction, automatic denoising and downsampling technology for 3D measurement data of tunnel construction profile surface, and processing and analysis of 3D measurement data of tunnel construction profile surface.

The operation and visualization platform for tunnel construction volume analysis and statistics is developed based on B/S technology and accessed by management and operation personnel through the browser of networked terminal devices. It is used to display the three-dimensional information of the tunnel contour surface and statistical information of various construction equations, mainly achieving high-precision statistical data query and visualization of key volume indicators such as over excavation and under excavation, support concrete quantity, and actual required lining concrete quantity based on the three-dimensional model of the tunnel contour surface.

The tunnel construction volume data management mobile application runs on mobile phones and tablet terminals, used to understand the current construction stage of the tunnel, real-time contour surface morphology, construction project volume, and other data anytime and anywhere.

2.2 System Functional Architecture

Based on the principles of relative independence, minimizing data dependencies, minimizing data redundancy, managing development needs, and implementing the system in stages, combined with the content and characteristics of this system, this system is divided into six functional modules: system management, project management, point cloud data management, point cloud computing analysis, data visualization, and report management.

1) System management module. This module mainly implements user management, permission management, message management and other functions of the system. The system takes into account both functional permissions and data permissions. Each user is assigned functional permissions based on their role in the project, and data permissions are set based on the principle that project data does not cross departments.

2) Project management module. This module mainly implements the functions of tunnel project information management, project user management, and project document management in the system. Project information management mainly involves the creation, deletion, and information entry of tunnel projects. Tunnel project user management is the correspondence between project department users and projects, granting specific personnel data permissions to ensure the security of project information. Project document management mainly realizes the functions of uploading, browsing, and downloading documents related to the project, and realizes the cloud storage of project materials.

3) Point cloud data management module. During the tunnel construction process, it is necessary to timely understand the current construction status. Therefore, point cloud data of the tunnel will be collected multiple times at different times, parts, and processes throughout the entire construction cycle. These data have characteristics such as massive, temporal, fragmented, and repetitive. This module achieves accurate, efficient, and intelligent fusion, storage, and management of point cloud data collected multiple times at different times, parts, and processes throughout the tunnel construction cycle.

4) Point cloud computing analysis module. This module mainly realizes the accurate reading and analysis of various design elements in tunnel construction, automatic denoising and precise downsampling of 3D measurement data of tunnel construction contour surface, and constructs a high-precision 3D model of tunnel construction contour surface. Based on the 3D model of tunnel construction contour surface, high-precision statistical data of key indicators such as over excavation and under excavation amount, support concrete amount, and actual required lining concrete amount are further calculated.

5) Data visualization module. This module mainly realizes the visualization of point cloud data and key engineering quantity data for tunnel construction. Through interactive graphics, the current

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situation of tunnel construction over excavation and over consumption can be intuitively, clearly and effectively conveyed, allowing for deeper observation and analysis of data.

6) Report management module. This module mainly realizes the automated generation of various engineering quantity reports for tunnel construction. Users can customize templates according to their actual needs, and the system automatically extracts data from the report template and processes it to generate a quantity report in PDF format.

3. Key Algorithms for System Implementation

3.1 Accurate Detection Method of Tunnel Overshooting

In order to improve the accuracy of tunnel undercuts detection, the system proposes an accurate detection method for tunnel undercuts. First, according to the design centerline and design section information of the tunnel, all points are projected to obtain the unfolded point cloud of the tunnel; then, based on the radial distance of each point after projection, the over-undercutting status of the tunnel is determined; further, the point cloud of the tunnel is processed in blocks, and the Delaunay triangular mesh construction method is used to build the TIN model of each block of the point cloud, as shown in Figure 2; finally, the TIN model of each triangle in the TIN model and its projection distance are calculated. calculating the volume enclosed by each triangle in the TIN model and its projected triangles on the projection plane, the volume of all triangles is summed up to derive the over-under-excavation volume of the tunnel. Meanwhile, in order to improve the computational efficiency, the system adopts a parallel computing method, which significantly improves the speed of the projection of the tunnel point cloud and the calculation of the square volume of the TIN model.

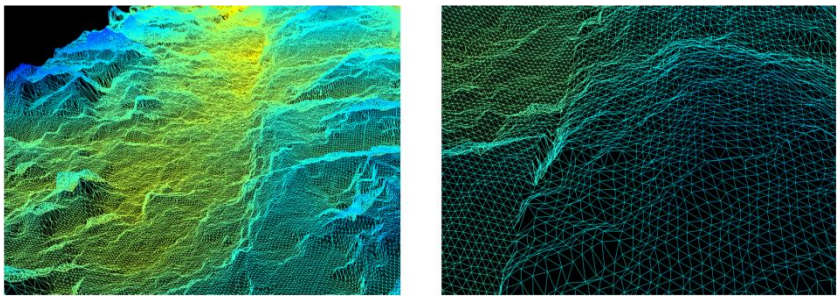

Figure 2. TIN model of point cloud

3.2 Intelligent Management Method for Massive Point Clouds

The system takes into account the three-dimensional spatial characteristics of the tunnel, and without changing the original point cloud distribution characteristics and accurately reflecting the geometric features, the point cloud data are thinned and denoised, and then progressive chunking is carried out at the three levels of mileage, grid, and time to realize the intelligent management of the scattered, time-sequenced massive point cloud data collected during the whole construction cycle of the tunnel, and the specific process and chunking are shown in Figure 3.

The system accurately, efficiently and intelligently integrates, stores and manages the massive, time-sequenced, fragmented and repetitive point cloud data acquired at different times, in different parts and in different processes during the whole construction cycle of the tunnel, finally forming a point cloud big data resource with standardized format, comprehensive information and convenient access, and then further establishing a 3D model of the tunnel contour surface, so as to ultimately achieve the results of the over- and underdredged amount of over- and underdredging, the amount of support concrete and the actual required lining amount, as well as the actual required lining amount. This enables high-precision calculation of key construction indicators such as the amount of over- and under-excavation, the amount of support concrete, and the amount of lining concrete actually required, providing a true, accurate, and traceable data base for tunnel construction management.

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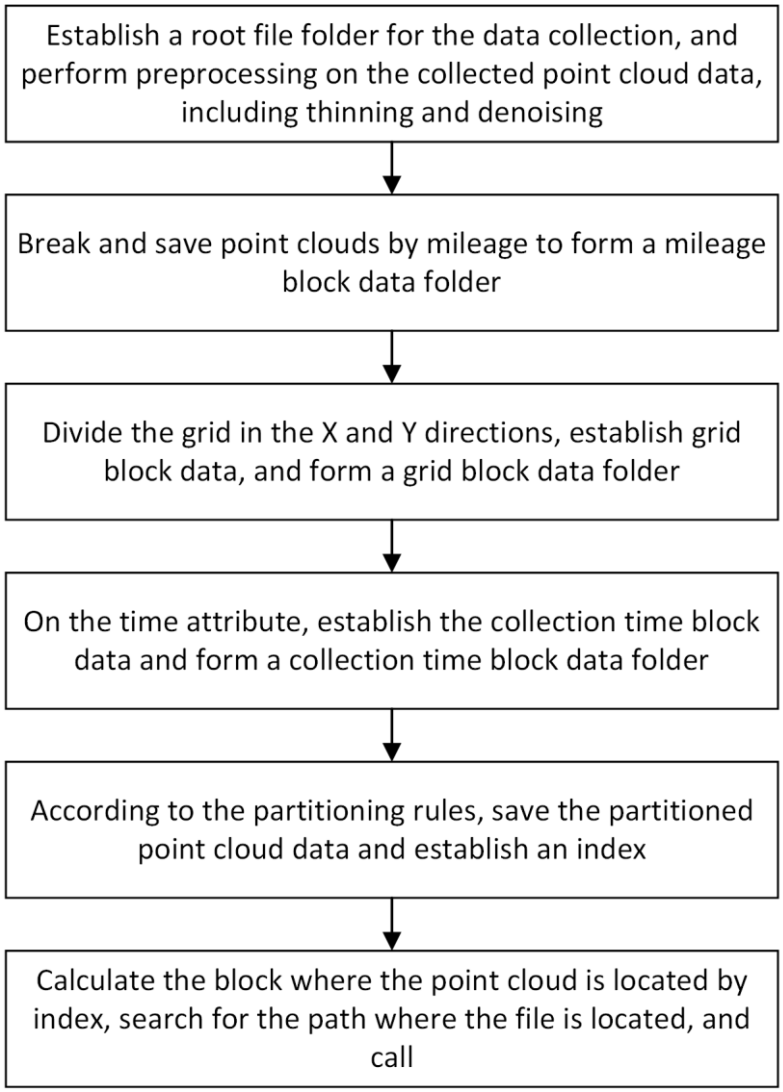

Figure 3. Massive point cloud intelligent management process

4. System Applications

After the development of the point cloud-based tunnel construction volume analysis management system was completed, it was tested and applied in the projects of Yukun Railway and Chengdu-Chongqing Central Railway, and the main applications of the system are as follows:

1) Excavation analysis. Figure 4 shows an example of statistical analysis of over-under-excavation volume in the current project, and the over-under-excavation of each mileage section can be viewed in detail from the page; Figure 5 shows an example of a detailed over-under-excavation report of a certain mileage section, and the cross-section diagram in the report can visualize the difference between the actual tunnel excavation contour surface and the design cross-section.Excavation analysis.

2) Initial support analysis. Figure 6 shows an example of the initial support flatness report for a certain mileage section. From the flatness distribution diagram, the initial support surface flatness of the tunnel in this section can be intuitively understood. Figure 7 shows an example of the statistical data of the theoretical volume of the initial support for the current project tunnel. From the statistical histogram, the comparison data between the theoretical volume and the actual volume in each mileage interval can be seen, which can be used by management personnel to accurately grasp the over-consumption situation in the construction project.

3) Secondary lining analysis. Figure 8 shows a mileage section of the secondary lining encroachment report example, from the cross-section diagram is very intuitive to view the second lining after the

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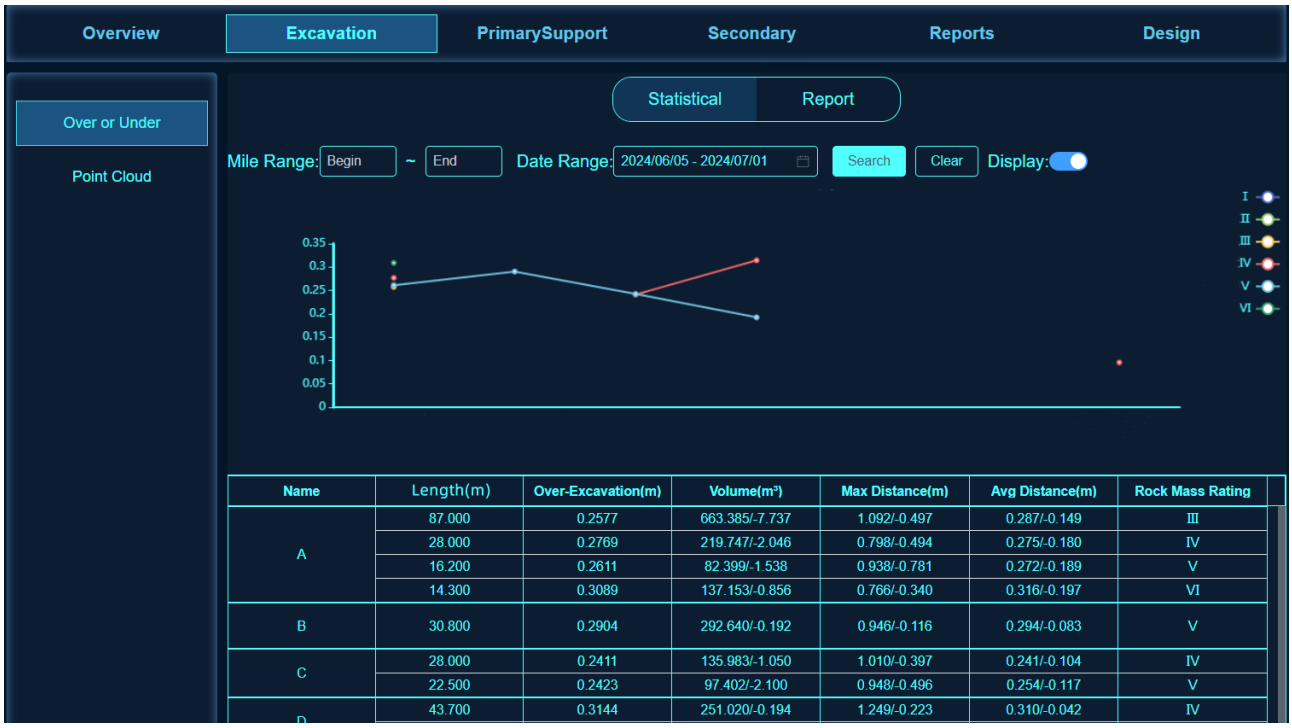
construction of the encroachment; Figure 9 shows a mileage section of the secondary lining thickness report example.



Name	Length(m)	Over-Excavation(m)	Volume(m³)	Max Distance(m)	Avg Distance(m)	Rock Mass Rating
A	87.000	0.2577	663.385/-7.737	1.092/-0.497	0.287/-0.149	III
	28.000	0.2769	219.747/-2.046	0.798/-0.494	0.275/-0.180	IV
	16.200	0.2611	82.399/-1.538	0.938/-0.781	0.272/-0.189	V
	14.300	0.3089	137.153/-0.856	0.766/-0.340	0.316/-0.197	VI
B	30.800	0.2904	292.640/-0.192	0.946/-0.116	0.294/-0.083	V
C	28.000	0.2411	135.983/-1.050	1.010/-0.397	0.241/-0.104	IV
	22.500	0.2423	97.402/-2.100	0.948/-0.496	0.254/-0.117	V
D	43.700	0.3144	251.020/-0.194	1.249/-0.223	0.310/-0.042	IV

Figure 4. Statistical analysis of over excavation volume

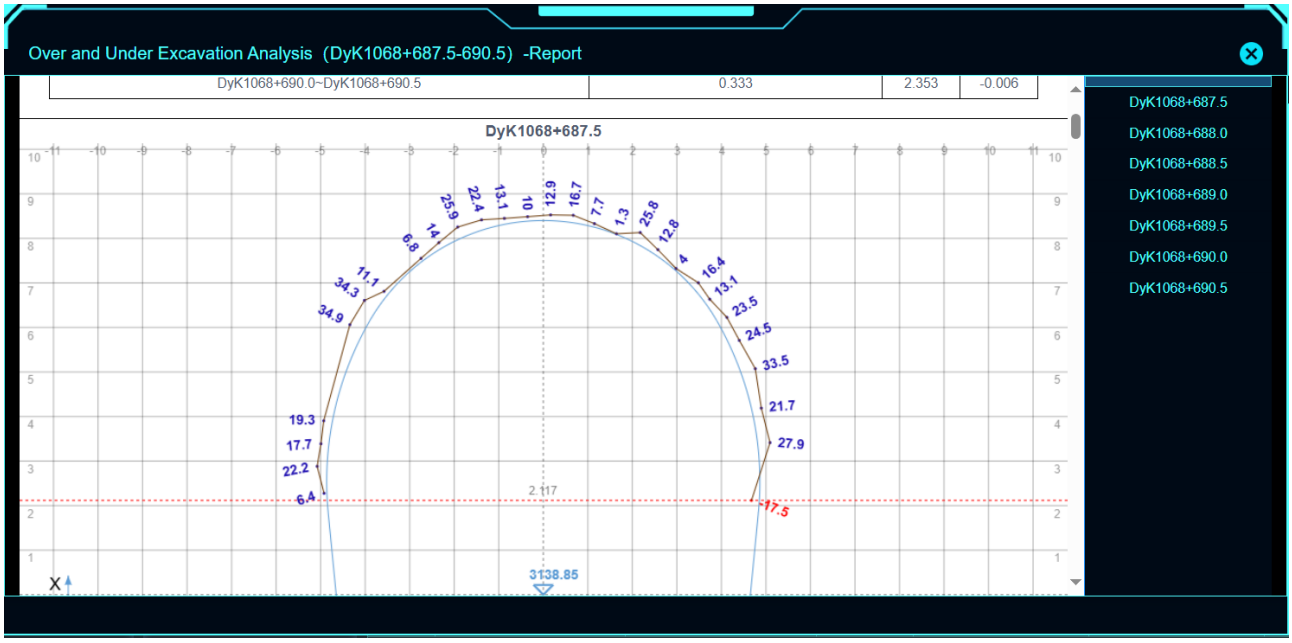


Figure 5. Detailed report on excessive and insufficient excavation volume

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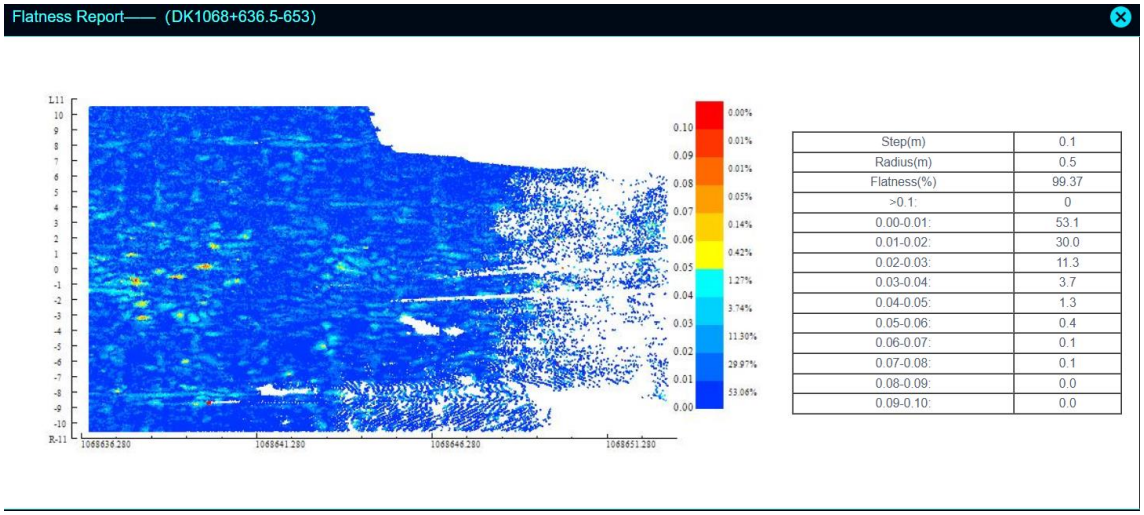

Figure 6. Example of initial flatness report

Figure 7. Statistical data on initial theoretical direction

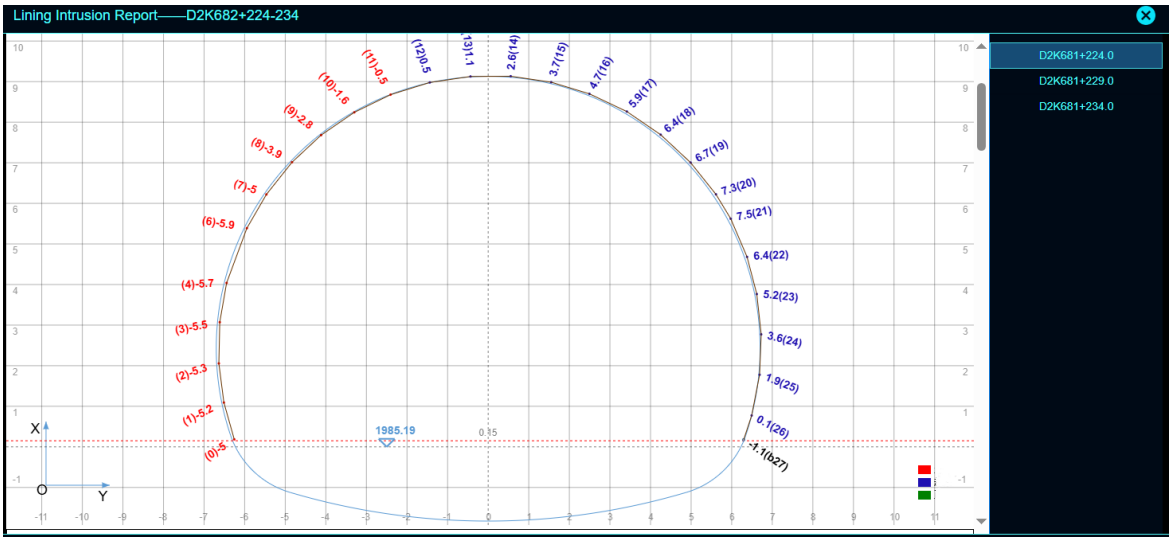

Figure 8. Secondary lining intrusion limit report

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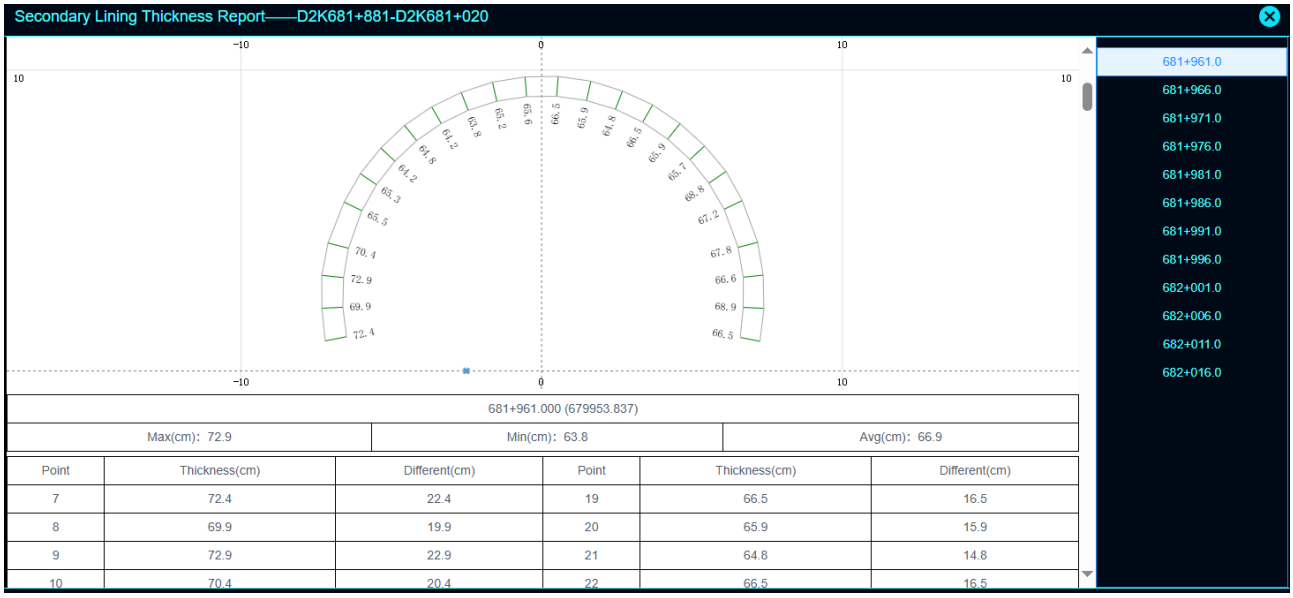

Point	Thickness(cm)	Different(cm)	Point	Thickness(cm)	Different(cm)
7	72.4	22.4	19	66.5	16.5
8	69.9	19.9	20	65.9	15.9
9	72.9	22.9	21	64.8	14.8
10	70.4	20.4	22	66.5	16.5

Figure 9. Secondary lining thickness report

5. Conclusion

The point cloud-based tunnel construction volume analysis and management system establishes a set of three-dimensional precision measurement of tunnel construction profile surface, automatic data analysis and processing, data application algorithm system and management and application process, realizes unified, efficient and orderly management of three-dimensional point cloud data of tunnel profile surface, and meets the goal of organic combination of "on-site surveying and mapping" and "construction management" based on the cooperation and interaction of desktop, webpage, and cell phone management terminal software. Based on the cooperation and interaction of desktop, webpage and mobile phone management software, the system meets the goal of organic combination of "on-site surveying and mapping" and "construction management" and has high practical value. Engineering tests show that the system can meet the demand for instant scanning, instant analysis and on-the-spot guidance of construction, and can calculate with high precision the amount of over- and under-excavation, the amount of support concrete, the amount of lining concrete and other key quantitative indicators of tunnel construction, and through detailed statistical tables and graphs, it can provide management and operation personnel with instant access to the accurate information of tunnel construction, thus guiding the adjustment and improvement of the construction parameters, and controlling the construction of tunnels. It can be used to guide the adjustment and improvement of tunnel construction parameters and control the over-excavation and over-consumption of tunnel construction.

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