3D GIS BASED LONG-DISTANCE PROJECT CONSTRUCTION PROGRESS VISUALIZATION

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ABSTRACT:

The construction progress of a long-distance project can generally be reflected by the percentage of the total length of the segmented project on the main line to the total length of the line. However, the way to express the construction progress based on the percentage is not intuitive enough and it is difficult to reflect the segmented project. Insufficient progress differences. This paper proposes a 3DGIS-based visualization method of long-distance project construction progress. Through regular project construction progress report, the completed line can be automatically generated. At the same time, the overall and local construction progress can be visually expressed through the superimposed display with the main line of the project and the three-dimensional terrain. The experiment combined with the engineering example of the Kunming section of Central Yunnan Water Diversion Project shows the visualization effect of the excavation progress of the water conveyance tunnel, and verifies the effectiveness of the method in this paper.
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1. INTRODUCTION

Long-distance projects mainly include water diversion projects, highway projects, pipeline projects, and power transmission projects. At present, there are a large number of long-distance projects under construction in China (Hong, 2017). Due to the characteristics of long-distance projects such as cross-regional, large investment, long construction period, many participating units, and complex influencing factors, progress problems are often prone to occur in the process of project construction. Therefore, integrating traditional Gantt charts, reports and other means, using advanced construction progress visualization methods, and assisting the accurate and visual simulation display of construction progress are of great significance for formulating construction organization design and improving construction progress management efficiency (Chen 2003).

With the rapid development of 3D rendering engine, 3D GIS, BIM and other technologies, the visualization of construction progress through 3D technology has become a research hotspot (Hartmann et al., 2008). Based on the Unity3D engine, Zhong Denghua and others developed a 3D visualization analysis system for the construction process of the asphalt concrete core rockfill dam under the network environment, and realized the remote analysis and real-time control of the construction progress of the asphalt concrete core rockfill dam (Zhong et al., 2013). Zhao Chunju et al. used the object-oriented graphics rendering engine OGRE to develop a visualization simulation system for the construction process of the roller compacted concrete dam, and realized the dynamic simulation and interactive browsing query of the whole process of the dam construction (Zhao et al.,2013; Li et al., 2011). Wang Xiaoling et al. established a three-dimensional parametric model of the pressure pipeline shaft of the diversion tunnel based on the Catia platform, and established the association between the three-dimensional model and the construction schedule, and realized the three-dimensional visualization of the tunnel construction progress (Wang et al., 2018). Based on the Naviworks platform, Mawlana et al. integrated the Microsoft Project schedule file to realize the construction schedule arrangement and 4D simulation of the expressway (Mawlana et al., 2015). Based on CityEngine, ArcSDE, SQL Server and other technologies, through the three-dimensional dynamic display of engineering construction and the synchronous update of construction process information, Geng Jing et al. achieved dynamic visualization management of avionics hub construction (Geng et al., 2017).

However, because game engines (such as Unity3D, Unreal, OGRE, etc.) and BIM design software (such as Catia, Revit, MicroStation, etc.) generally do not have the tile data generation, loading and scheduling mechanism in GIS software, they cannot carry massive 3D terrain and 3D model data, which makes it difficult to visualize the construction progress of long-distance projects (Rafiee et al., 2017). At the same time, 3D progress visualization methods based on solid modelling are often limited by the minimum granularity of engineering solid model division. For example, in the engineering unit division system of water conservancy and hydropower projects, after the unit engineering modelling is completed, the construction progress of the unit engineering itself can be simulated only if the unit engineering model is divided into smaller granularities, resulting that it is unable to adapt to the refined schedule management needs of the project site. Therefore, in order to realize the 3D visualization of the construction progress of long-distance projects, further technical exploration is required.

2. TECHNICAL ROUTE

This paper proposes a 3DGIS-based construction progress visualization method for long-distance projects. Based on the

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construction area DEM (Digital Elevation Model), construction area DOM (Digital Orthophoto Map), project bidding division, engineering design line and other data, combined with regular construction progress reporting, the completed line vector of each bidding section is realized. At the same time, through the superimposed display with the three-dimensional terrain and engineering line vector, the overall and local construction progress of the project can be visually expressed. The key steps include: regularly progress reporting, 3D terrain construction, completed line generation, and terrain-draped line rendering. The overall technical route is shown as Figure 1.

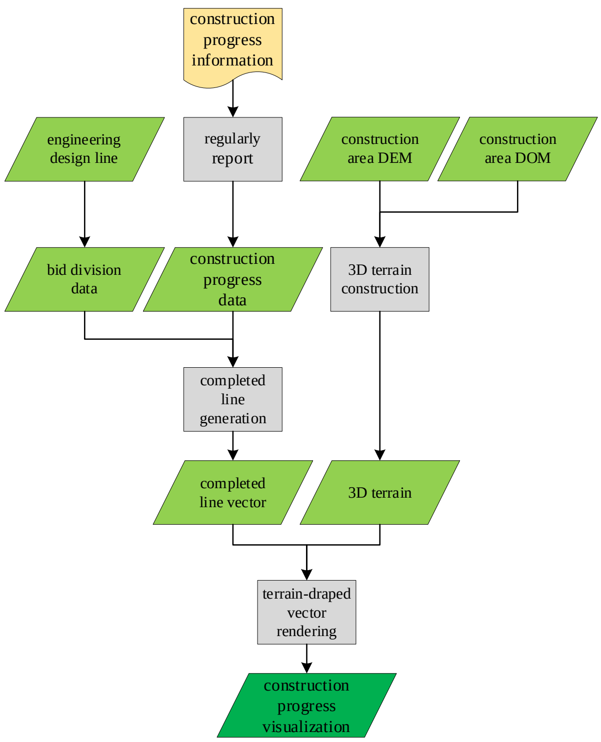


Figure 1. Technical route

2.1 Regular progress report

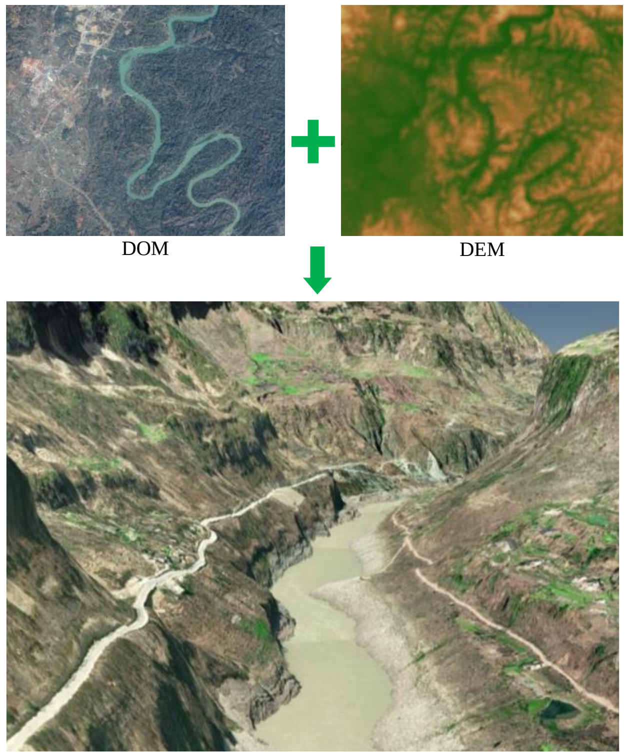
The percentage of construction progress of long-distance projects can be approximated as the ratio of the sum of the lengths of the completed lines of each bid section to the total length of the engineering lines. The length of the completed line of each bid section comes from the regular construction progress report data of each bid section. The completed line length is obtained by accumulating the reported construction distances in each cycle since the start of construction. For typical tunnel excavation projects, construction progress information is generally submitted in the form of daily excavation reports, as shown in Table 1 below.

Date	3-10	3-10
Working face	Upstream of the XX Hole 7#	Downstream of the XX Hole 7#
Allowed excavation distance	12	12
Excavation distance of the group	2	2
Excavation distance today	4	4
Cumulative excavation distance	132.5	112.5

Table 1. Example of daily tunnelling length report

2.2 3D Terrain Construction

In order to visually display the geographical environment in the construction area and better serve the visualization of the construction progress of long-distance projects, it is necessary to obtain high-precision DEM data and DOM data in the construction area, and use GIS software for data pre-processing, tiling and publishing. Finally, through the 3DGIS platform, the three-dimensional topography can be displayed (Guo, 2019).



3D Terrain

Figure 2. 3D terrain construction process

2.3 Completed line generation

The purpose of the completed line generation is to intercept the vector data of the completed line from the overall design line vector data of the project based on the bid division and the length of the completed route. Figure 3 shows a schematic diagram of the completed line under three different construction methods. Among them, forward construction means that the project is constructed along the start and end direction of the design line; reverse construction means that the project is constructed in the reverse direction along the start and end direction of the design line; bidirectional construction means that the project is simultaneously constructed from somewhere in the middle to the start and end direction of the design line. The situation of simultaneous excavation of upstream and downstream in tunnel engineering corresponds to Figure 3(2). With the continuous reporting of the construction progress and the increase of the length of the completed route, the vector data of the completed route of the project also gradually becomes longer along the design line.

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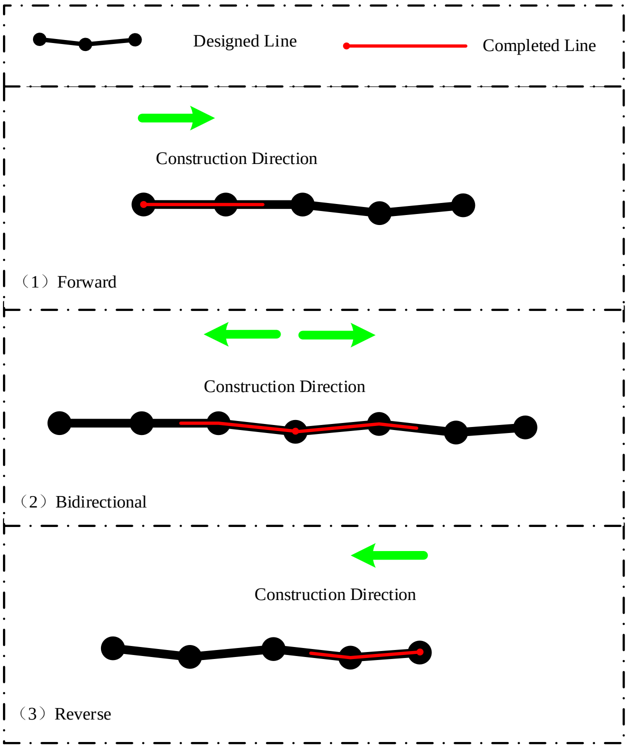
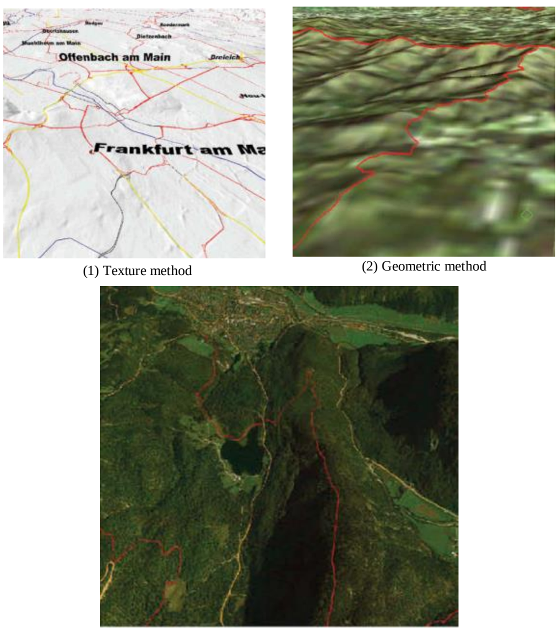


Figure 3. Schematic diagram of completed line generation

2.4 Terrain-draped vector rendering

After obtaining the vector data of the completed line, the three-dimensional terrain-draped vector rendering method can be used to visualize the completed line data, and with the continuous reporting of the construction progress, the display effect of the completed line on the ground can be dynamically updated, so as to achieve the real-time progress visualization. At present, there are three main methods for 3D rendering of terrain-draped vector: texture based rendering method, geometry based rendering method, and stencil shadow volume based rendering method (Yan et al., 2008).



(1) Texture method (2) Geometric method (3) Stencil shadow volume method

Figure 4. Examples of 3D rendering using different techniques.

The main idea of the texture-based method is to process the vector data into a texture image, and then superimpose it on the three-dimensional terrain through the texture mapping method. According to the primary theory, linear symbols are integrated into the texture image, with the integration generally executed as part of the preprocessing (Dollner et al. 2000). Terrain LOD does not impose issues as textures are independent of the terrain shape. However, transitions between neighbor tiles of different resolutions must be handled, and the texture resolution is prone to the occurrence of aliasing artifacts (Sun, 2016).

The main idea of the geometric method is to project each vertex of the vector data along the Z direction, then intersect these projections with the 3D terrain grid, and connect the intersections in turn to form lines and arcs that can be attached to the ground (Deng and Xu, 2013). This technique relies on an irregular terrain tessellation, demanding high resolution locally to represent the terrain features (Frasson et al. 2018). Precomputing the vertices at each level of the terrain model is recommended, but the number of vertices will be greatly increased with the improvement of terrain resolution (Zhou et al. 2016).

The basic idea of stencil shadow volume method is to perform stencil test when drawing vectors, so that those pixels located in the shadow area of the vector pass the stencil test, and the pixels located outside the shadow area do not pass the stencil test, thereby generating a ground-based projection of the vector. Typically, vector data is extruded into a polyhedron and used to create a mask in the template buffer. The mask area corresponding to the vector feature is rendered, and the final template contains the information of whether the pixel is in the vector feature (Yang et al. 2011). This method requires multiple render channels and the geometry must be pre extruded. Styles are limited because it is difficult to retain intersection information.

The comparison of these three algorithms is shown in the table 2 (She et al., 2018). From the comparison in the table, it can be seen that the stencil shadow method has low memory usage and high rendering efficiency, and is a more ideal terrain-draped vector rendering algorithm for this paper.

Method	Texture method	Geometric method	Stencil shadow volume method
Algorithm Complexity	Low	High	Middle
Memory usage	High	Low	Low
Rendering efficiency	Middle	Slow	Quick
Overhead or puncture	None	Might have	None

Table 2. Terrain-draped Vector Rendering Methods

3. THE VECTOR LINE GENERATION ALGORITHM OF THE COMPLETED LINE

Based on the length of the completed line, dynamically obtaining the vector data of the completed line is the key to realize the visualization of the construction progress of the long-distance project. It can be seen from Figure 3 that the vector extraction problem of completed lines in the case of bidirectional construction consists of a forward construction problem and a reverse construction problem. The difference between forward construction and reverse construction for the extraction algorithm of the completed line vector is only in the input order of the vertex data of the design line. This section describes a vector generation algorithm for a completed line that can extract the completed line vector given a design line, a construction start point, and a completed line length.

As shown in Figure 4, it is known that the vertex sequence of the engineering design line starting from the construction starting point is $\{P_i\}, (1 \leq i \leq n)$, the coordinates corresponding to each vertex are (x_i, y_i), and the length of the completed line is L. Set O as the origin of the coordinates, the end point of the completed line is located at the distance L and outside the nearest vertex P_m, which denoted as point P with coordinates (x, y). So $P_m P = l$, which satisfies $0 < m < n$, $0 \leq l$.

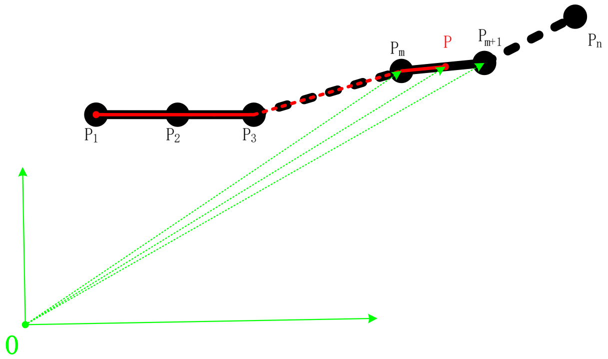


Figure 4. Schematic diagram of completed line calculation

The distance S_m from the construction start point P_1 to P_m is expressed as follow:

$$S_m = \sum_{i=2}^{m} (\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}) \quad (1)$$

Obviously, $S_m < L < S_{m+1}$, When substituting equation (1) into, it is an indeterminate equation. According to the definition, the unknown parameter m of this equation has one and only one integer solution, which can be easily obtained by cyclic calculation experiments through computer programming. Then according to $l = L - S_m$, the value l can be calculated. Further, let $\alpha = P_m P / P_m P_{m+1}$, namely:

$$\alpha = \frac{l}{\sqrt{(x_{m+1} - x_m)^2 + (y_{m+1} - y_m)^2}} \quad (2)$$

According to the basic operations of plane vectors, there are $\overrightarrow{OP} = \alpha \overrightarrow{OP_{m+1}} + (1 - \alpha)\overrightarrow{OP_m}$, so:

$$\begin{cases} x = \alpha x_{m+1} + (1 - \alpha) x_m \\ y = \alpha y_{m+1} + (1 - \alpha) y_m \end{cases} \quad (3)$$

Substitute equation (2) into equation (3) to calculate the coordinates of P. Then the vertex sequence of the completed route vector $\{P_1, P_2, \ldots P_m, P\}$ is calculated.

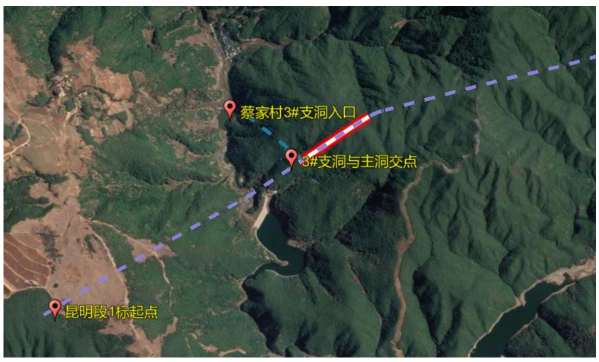
4. CASE STUDIES

In order to verify the effect of the long-distance engineering construction progress visualization method proposed in this paper, the tunnel excavation progress of the Kunming Section 1 of the Central Yunnan Water Diversion Project was selected to conduct a visualization experiment.

The Central Yunnan Water Diversion Project is a strategic basic project for the sustainable development of Yunnan Province. The project draws water from the Shigu section of the upper reaches of the Jinsha River to supply water for urban life and industry in central Yunnan, taking both agriculture and ecology into account, so as to solve the serious problem of water shortage in Yunnan Province. Construction Bid I of Kunming Section is the section with the longest line, the largest investment and the most difficulties in the Kunming section of the Central Yunnan Water Diversion Project. The total length is 21.267 km, and 92% of the project is tunnels, including 6 tunnels, 5 construction branch holes, and 1 inverted siphon. The longest single tunnel is more than 16 km. Figure 5 shows the effect of superimposing the general layout of the project and the route trend on the three-dimensional terrain.

Figure 5. Kunming section construction bid I

Based on the reported data of the construction progress at the intersection of the 3# branch tunnel and the main tunnel of Caijiacun and the entrance of the Songlin Tunnel, the accumulated excavation distantce at a certain moment was selected, and the vector line generation algorithm of the completed line was used to generate the vector data of the completed line. Together with the line data of the main hole and the line of the branch hole, a visual expression is carried out on the three-dimensional terrain through the vector drawing technology of the stencil shadow volume method. The specific effect is shown in Figure 6.



（1）Construction progress of 3# branch tunnel of Caijiacun Tunnel

（2）Construction progress of Songlin Tunnel

Figure 6. Branch tunnel construction progress visualization

The long-dotted line in the picture is the main tunnel line of Kunming Bid I, the short-dotted line is the construction branch line, and the white solid line with red edge is the partially completed line. It can be seen that through the three-dimensional terrain and terrain-draped vector rendering, the completed length of each branch hole and the specific location of the construction can be visually displayed. At the same time, with the help of timeline control and graphic reports, reading the construction progress data in the specified time period and updating the vector grounding data of the completed lines can realize the dynamic simulation of the construction progress, thus enriching the visualization effect of the construction progress, and providing strong support for improving the progress management of long-distance projects.

5. CONCLUSION

This paper proposed a construction progress visualization method based on 3DGIS, analysed the technical route of the method, focused on the automatic generation algorithm of the completed line and achieved good results.

Compared with the traditional visualization method of construction progress based on 3D solid modelling or BIM modelling, the advantages of this method are:

1) The generalized expression of long-distance engineering is realized through the display of vector lines on the ground. The algorithm is more efficient, and the expression is more efficient.

2) The progress report data of the project site can be reflected in the visual scene in time, which is closely related to the project progress management requirements.

Further research can consider the variation of the engineering line along the space Z direction to achieve an accurate expression of the construction progress.

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