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Research Article

Research on the 3D Fine Modeling Method of In-Service Road

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To achieve the digitization of all traffic infrastructure elements and enable three-dimensional digital representation of physical facilities, a multilevel road three-dimensional reverse modeling method is proposed based on road point cloud data obtained by a vehicle laser scanning system. First, based on the distribution characteristics of each target structure in the road scene and the modeling requirements, a levels of detail (LOD) modeling specification is designed, and the required feature data format for each level is defined. Next, the three-dimensional characteristic parameters needed for modeling are extracted from the vehicle point cloud data. Finally, the continuous quadrilateral algorithm is used to reconstruct the road model, the topological structure relationship algorithm is used to reconstruct the intersection model, and the instantiation lofting technology is used to reconstruct the rod-shaped target model, all based on the three-dimensional modeling platform. This approach allows for the rapid reverse reconstruction of three-dimensional road models with different LOD levels. The point cloud data of two sections of urban roads with different slopes and one section of expressways were modeled and compared with the original vehicle-mounted laser point cloud data. The data volume of different level models decreases with decreasing model fineness, and the LOD1 level model has the highest similarity with point cloud data, at approximately 92.17%. The similarity of LOD2 and LOD3 decreases in turn, at 82.91% and 75.25%, respectively. For flat or undulating roads, the overall accuracy of the nearest point distance between different levels of road models and point cloud data is better than 10 cm, significantly higher than that of traditional manual modeling. The results demonstrate that vehicle mobile laser scanning technology provides new modeling data for the rapid realization of three-dimensional reverse reconstruction of large-scale traffic infrastructure. Automatic modeling technology can effectively improve modeling efficiency, reduce data redundancy, and ensure model quality.

1. Introduction

With the continuous development of China's economic construction, transportation highway construction has made great achievements. According to the statistical bulletin of transportation industry development in 2021, the total national highway mileage was 5.2807 million kilometers. In the outline of digital transportation development plan issued by the Ministry of Transport, it is clearly pointed out that the full-factor and full-cycle digitization of transportation infrastructure should be realized, and the three-dimensional digitization of physical facilities should be realized. Under the premise of reducing data redundancy and ensuring the quality of the model, the rapid realization of three-dimensional reverse reconstruction of large-scale traffic infrastructure has become a research hotspot.

At present, the most common three-dimensional road model is the BIM model created in the design stage, which is widely used in facilities management, energy performance analysis, project planning, and other aspects [1–3]. However, the BIM model created in the design stage is often inconsistent with the actual construction situation, which cannot well support the follow-up management services. At the same time, some stock road networks also lack BIM design data. Therefore, it is necessary to carry out reverse three-dimensional rapid reconstruction of this road infrastructure and establish a new digital base for road infrastructure.

Three-dimensional laser scanning technology has been widely used in high-precision digital map construction, semantic segmentation of road objects in the whole scene, and other fields [4–6] because of its advantages of high precision, fast speed, noncontact, and rapid acquisition of accurate three-dimensional space information of the measured object. Currently, the method of using laser scanning point cloud for road 3D measurement is also relatively mature. While providing road 3D coordinate information, intensity information, and echo information, it can effectively distinguish various targets on the road and provide high-precision and high-density basic data for road 3D fine reduction.

Some scholars have carried out relevant research on road feature extraction, which is based on the characteristics of road 3D laser scanning data. Fang et al. [7] proposed an attention model of vehicle laser point cloud line classification map based on spatial context information. The attention mechanism is constructed based on the geometry, topology, and spatial structure of the line to dynamically update the node characteristics and realize the fine classification and vector extraction of the line. A road boundary extraction method of vehicle-borne laser point cloud based on discrete point Snake is put forward [8], which realized the extraction of road boundary with different shapes in various complex urban environments. In addition, the existing LiDAR360, MultiPointCloud, TopoDOT, and other software can also realize the road three-dimensional target feature extraction, which provides a new fine data support for road automation modeling [9]. It solves the problem that the discrete point cloud itself does not have semantic information [10, 11], and it cannot be based on the spatial coordinates of point cloud data and other attributes, such as intensity and color to reach semantic understanding, recognition of structured semantics, and classification information. However, there are relatively few studies on 3D rapid reconstruction of extracted feature data. Elberink [12] proposes an automated 3D modelling method for complex road interchanges based on airborne point cloud data combined with 2D topographic map data to automatically acquire 3D topological objects. Wang et al. [13] uses 2D GIS road centreline data to generate a 3D road network model, but it requires high data accuracy and is less adaptable for roads with certain undulations or width variations. Cura et al. [14] generated a road model, which is based on GIS data. It can generate a road network according to the road axis and generate multilevel roads with different widths according to custom materials. Wilkie et al. [15] proposed an effective method to enhance the road map from the GIS database. It can quickly create a 3D road model with consistent geometry and topology, which provide important road features for traffic simulation. Although the above two methods can quickly generate the road model with the help of simple point-line characteristics, the accuracy of the model is low. Besides, the general adaptability to undulating roads or complex intersections is not ignored.

In view of the above problems, this paper designs a levels of detail (LOD) model for road target reconstruction based on the vehicle laser point cloud data and the structural distribution characteristics of the target in the road scene. The required feature data are extracted according to the reconstruction details of the model to realize the three-dimensional reverse modeling of the road.

2. Road LOD Model Design

2.1. Feature Description of Ground Objects. Road scenes are complex and diverse, involving the geometric position, feature shape, and relationship of multiple ground objects. Therefore, before the road model reconstruction, it is necessary to decompose the road into independent model objects and determine the feature data of each target. The ground feature data mainly include the spatial distribution characteristics and geometric structure characteristics of the target [16]. Spatial characteristics include the overall distribution of ground objects in three-dimensional scenes, the geographical location and orientation of ground objects, and the topological relationship between objects. A geometric feature is the surface geometry of various geographic entities, such as size, structure, etc. Specific features are shown in Table 1.

2.2. LOD Model Design and Feature Extraction

2.2.1. LOD Model Design. The traditional 3D data model abstracts the spatial object into four spatial geometric types, namely point, line, surface, and body, with few concepts of multilevel details. With the wide application of 3D models, the real performance of more and more complex scenes poses challenges to the system's hardware and software performance, and there is also a higher demand for manpower, material resources, and other costs. It is difficult to establish a general LOD model with a series of scales to meet different application requirements. The feasible way is to design a specific LOD model for specific application requirements [17].

The key problem in establishing a LOD model is to determine the reasonable level of detail content, including the level of detail, precision, and modelling method. In different BIM standards, building information is usually organized in a layered structure. In the city geographic markup language (CityGML) standard all models can be divided into five different levels of coherence detail (LOD), and with the improvement of the level of detail, we can get more details about geometry and theme. It can not only show the graphic appearance of the city model but also take into account the semantic expression [18]. The urban 3D geographic information model data standard divides the model into LOD1-4 four levels. LOD1 level is the super fine model, whose fine degree is the highest, the LOD4 level is the frame model, whose fine degree is the lowest. The model manifestation divides into three kinds: the detail model performance, the main model performance, and the standard model performance three kinds. However, there is no detailed description of the road details in the existing standards.

Table 1: Feature description.

Targets	Distribution characteristics of ground objects	Relationship with road topology	Geometric features
Pavement	It has a minimum elevation throughout the entire road scene, showing a planar distribution	—	Smooth pavement, high density, and uniform distribution of the scanning point cloud
Mark line	It is generally located on the road, and the height undulates with the road height, presenting the linear distribution	Being contained	Most shapes are rectangular or arrows
Curbstone	It is generally located at the edge of the isolation zone, between the pavement and the sidewalk, and varies with the fluctuation of the road, showing a linear distribution	Real intersection, handover, vertical	Most of the shapes are cuboid or ellipsoidal with a planar structure
Planting	It is generally located in the center of the road or between the sidewalk and the road surface, showing a surface distribution	Real intersection, handover, vertical	Most shapes are regular cuboids, usually rectangular or semicircular at both ends
Roadside plants	It is on the sidewalk or in the isolation zone at a certain interval	Real intersection, handover, vertical	Point cloud distribution discrete, irregular shape
Guard rail	It is generally located in the center or on both sides of the road, presenting a linear distribution	Real intersection, handover, vertical	Mainly composed of horizontal rods, columns, and vertical rods, mostly round or square tubes
Road lamp	It is generally located on both sides of the road, and the head of the lamp faces the inside of the road with an azimuth angle	Real intersection, handover, vertical	It is composed of a lamp pole, lamp head, and lamp frame. The lamp pole is cylindrical, and the lamp head is irregular
Sign board	It is generally located on both sides of the road and within the road edge, toward the inside of the road, and there is azimuth	Real intersection, handover, vertical	The rod is a slender cylinder with a rectangular, circular, or triangular face
Signal light	It is usually located on both sides of the road, with lamppost toward the inside of the road and there is an azimuth	Real intersection, handover, vertical	Mainly composed of a lamp pole, head, and signal lamp, the irregular shape
Sidewalk	It is located on both sides of the road, with a surface distribution	Real intersection, handover, parallel	Mainly composed of blind and sidewalk, mostly regular cuboid shape

Therefore, combined with the distribution characteristics of road target structure and the actual modelling requirements, this paper designs a multidetail level modelling specification for road. The model is divided into agent model, the standard model, and detail model. According to the structural integrity of the overall model, the road detail level is divided into LOD1, LOD2, and LOD3 levels, corresponding to three discrete models which are the road network model, road rough model, and road fine model. The extraction and modelling rules of multilevel point cloud feature data obtained on demand are formed to reduce unnecessary vertices and patches redundancy, reduce the amount of model data, and effectively support the rapid modelling of road 3D models at different levels of detail. The effect is shown in Figure 1.

Among them, LOD3 level requires the highest fineness of the model, while ensuring the fineness of a single model size, considering the structural integrity of the whole road scene. Therefore, each target model requires detailed model performance, which is suitable for fine management and analysis of a single road. The LOD2 tier has been reduced in terms of individual model size granularity and overall model structural integrity, retaining the detailed models of road surfaces, pavements, and green belts in the LOD3 tier but with a slightly lower model size granularity, with kerbs, guardrails, markings, signage, and street lights suitable for 3D visualisation of roads in larger scenes. The LOD1 level has the lowest precision, which only retains the three main features of road surface, curb stone, and sidewalk in the LOD2 level, and is suitable for the three-dimensional visualization of road model at a large-scale road network level. In addition, based on the model manifestations at different LOD levels, the structural data needed for modeling are further clarified, such as node spacing, main structure, detail structure, and other parameters. The detailed design of the LOD model is shown in Table 2.

2.2.2. Feature Extraction. In order to realize the one-time extraction of road space feature data and a variety of demand production, it is necessary to extract the finest feature data structure in the road scene based on the point cloud data processing software, establish the feature database, and output the feature data of various targets to the standardized modeling data after preprocessing the 3D laser scanning data.

According to the structural feature data extraction requirements of each target in the road scene, it is necessary to preprocess the vehicle three-dimensional laser scanning data, including point cloud denoising, point cloud segmentation, point cloud strength enhancement, etc. Then extract all kinds of feature data based on the point cloud, mainly divided into point target, line target, and surface target. The point target mainly includes the supporting pole and street lamp pole of the sign board. It is necessary to extract the spatial position, azimuth, and height information and store the information in the GIS vector point layer data. Line target mainly includes road boundary, green belt and sidewalk boundary, curb, etc. It is necessary to extract three-dimensional boundary line, target height, and other information and save it in GIS vector line layer data. The surface target mainly includes the marking line and the label contour. The closed line is collected in the three-dimensional scene, extracted by converting it into surface data, and saved in the GIS vector surface layer data. The effect is shown in Figure 2. Finally, according to different LOD requirements, the GIS vector data is outputted as structural modeling feature data to support automatic modeling.

In the figure, the white vector line is the boundary of the surface features, the contour of the road marking line, and the contour of the signboard; the blue represents various types of support rods and the green represents various types of equipment.

3. Key Technique of Automatic Modeling

3.1. Consecutive Quadrilateral Pavement Reconstruction. In order to solve the problems of difficult elevation control, large error, and low efficiency in manual modeling of pavement, this section aims to analyze the data structure of the pavement model and realize the automatic modeling of pavement at different LOD levels. The road plane alignment structure and road elevation information are combined, and the simple three-dimensional road alignment is composed of the edge line and the road center line. The continuous quadrilateral reconstruction of pavement and the smoothing method for curves are given.

Consecutive quadrilateral reconstruction is the process of constructing a quadrilateral mesh by grouping the three-dimensional point data on both sides of the road and connecting them sequentially according to the closed quadrilateral rules. As shown in Figure 3, the outer edge points of the upper and lower roads are stored in arrays A and B, respectively. The data of the above rows are taken as an example. Firstly, the spline line is created from the starting point $i = 1$, and the points $A[1]$, $A[2]$, $B[2]$, and $B[1]$ are connected into a quadrilateral, $i = i + 1$. Then traverse the remaining points in turn until the completion of the last set of data quadrilateral connections; finally, the spline line is transformed into an editable polygon and the actual pavement material is given. The principle of downward road reconstruction is the same as that of upward road.

In the modeling of curved roads or road intersections, there may be unsmooth phenomena in the curved area. In order to improve the visual effect of the model, this paper interpolates the data of the road side line and the center line by solving the circular parameters of the curved space to achieve a smooth curved road. As shown in Figure 4, a, b, and c are three points on the center line of the bend; O is the center of the space circle where the three points are; R is the radius of the space circle; $\alpha 1$, $\alpha 2$, and $\alpha 3$ are the three azimuth angles from the center O to the center line points a, b, and c, respectively; and the cross points between a, b, and c are the encrypted interpolation points on the circular curve (see Algorithm 1).

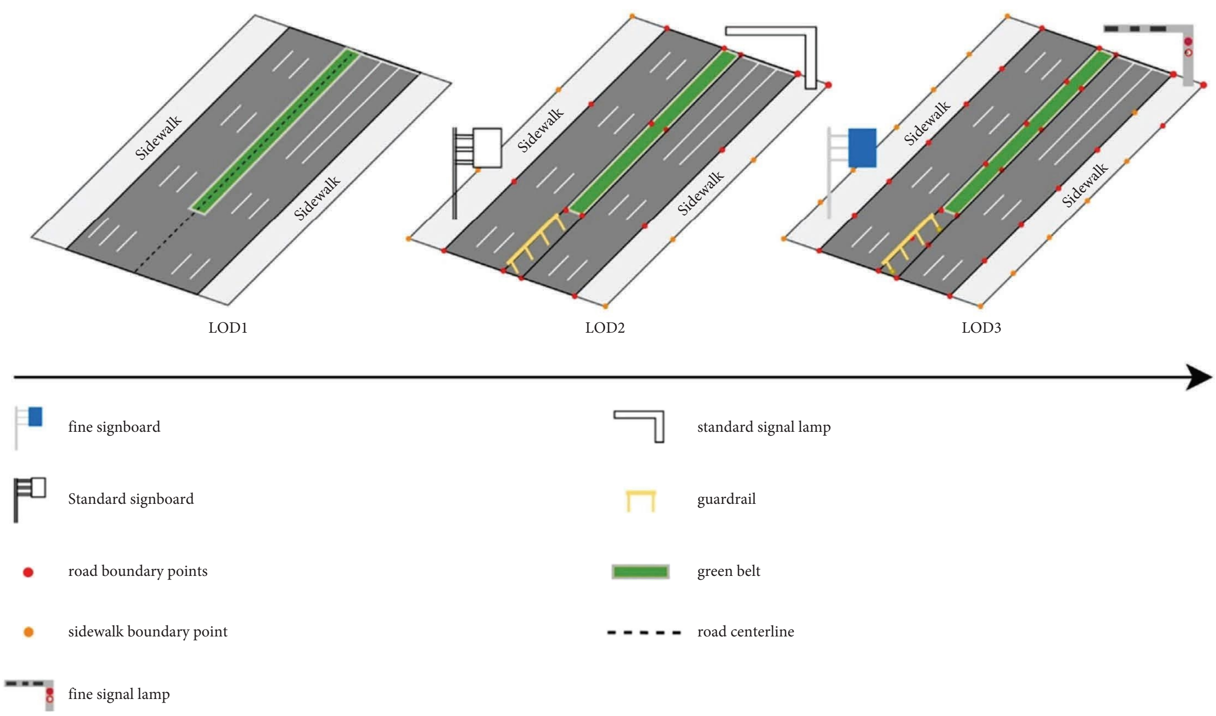


Figure 1: Road LOD model.

The specific smoothing algorithm is as follows:

$$R = \sqrt{(x - a_1)^2 + (y - b_1)^2}, \quad (1)$$

$$\begin{cases} P_I[X] = b[X] + R \times \cos O_i, \\ P_i[Y] = b[Y] + R \times \sin O_i, \\ P_i[Z] = a[Z] + (b[Z] - a[Z]) \times \dfrac{i}{n}. \end{cases} \quad (2)$$

3.2. Reconstruction of Topological Structure of Intersection

3.2.1. Three-Dimensional Linear Design of Intersection. For intelligent transportation and high-precision navigation application services, it is necessary to accurately extract road-connected intersections for road digitalization and interrupt at road corners. Road intersections usually include T-shaped intersection, Y-shaped intersection, and cross intersection. In highway engineering design specifications, road intersections are generally composed of straight roads, curved roads, and quasi-triangles. The key to the design of these components is the middle line of the driving lane. Based on this, this paper designs an intersection segmentation and reconstruction structure as the basic structure of road three-dimensional linear reconstruction.

As shown in Figure 5, the center point of the cross intersection is set as O, A, B, C, and D are the center points of the intersection and the common side of the straight road, and a, b, c, and d are the road conflict points. A, a, and B are regarded as the three points on the circle with O' as the center, and $O'A$ as the radius, and they are connected by curves to form a circular curve AB. The points with the same properties are the same. Intersections are divided into eight parts I–VIII, of which parts I–IV are a triangle-like region surrounded by a circular curve and two straight lines, and parts V–VIII is a four-section curved road.

The plane structures of a T-shaped intersection, Y-shaped intersection, and cross-shaped intersection are similar. T-shaped intersection is divided into five parts I–V. Region I is a straight road; regions II and III are triangular regions; and regions IV and V are curved roads. Y-shaped intersection is divided into six parts I–VI. Regions I, II, and III are curved roads, and regions IV, V, and VI are triangular regions.

3.2.2. Topological Structure Relation Reconstruction. According to the 3D linear structure design of the three intersections, each intersection is divided into several curved roads A, triangular area B and straight roads C, and processed, respectively, as shown in Figure 6(a). Cross intersections consist of four A regions and four B regions, T intersections consist of two A, two B, and one C regions and Y intersections consist of three A regions and three B regions, as shown in Figure 6(b). The triangular region B is reconstructed by the radial continuous triangle reconstruction method. Firstly, the data of the inner coordinate points of the bend are stored in array A. Starting from the starting point $i = 1$, three points $A[i]$, $A[i+1]$, and O are connected in turn to obtain a closed triangular region. Then $i = i + 1$, traverse the remaining data points in turn, until $A[n-1]$, $A[n]$, and O three points complete the triangle connection and realize intersection model reconstruction.

Table 2: Detailed design of the road LOD model.

Classification	Manifestation			Structural feature data		
	LOD1	LOD2	LOD3	LOD1	LOD2	LOD3
Pavement	Agent model	Detail model	Detail model	Overall modeling of road centerline	Road boundary point spacing straight 8 meters, bend 4 meters	Road boundary points 4 meters straight, 2 meters bend
Curbstone	Agent model	Standard model	Detail model	The approximate size and point spacing are the same as the pavement boundary	Standard section; point spacing identical to road boundary	Section contour point, point spacing and road boundary
Sidewalk	Agent model	Detail model	Detail model	Same as the pavement	Height, boundary point spacing straight edge 4 meters, bending edge 0.6 meters	Height, boundary point spacing straight edge 2 meters, bending edge 0.3 meters
Planting	Agent model	Detail model	Detail model	Same as the pavement	Height, boundary point spacing and sidewalk	Height, boundary point spacing and sidewalk
Guard rail	No	Standard model	Detail model	—	Standard style, centerline spacing identical to road boundary	Height, centerline spacing and road boundary
Reticule	Standard model	Standard model	Detail model	Indicator markings	Reticule	Standard model
Sign	No	Standard model	Detail model	—	Mark three-dimensional coordinates, azimuth, sign type	3D coordinates of sign, azimuth angle, sign type, sign outline and content
Facility	No	Standard model	Detail model	—	Facility three-dimensional coordinates, azimuth, facility type	3D coordinates of rod, azimuth angle, facility type, rod height
Equipment	No	Standard model	Detail model	—	3D coordinates of equipment, azimuth and type of equipment	3D coordinates of equipment, azimuth, equipment type, equipment height
Road side plants	No	Standard model	Detail model	—	Position of trunk	Stem position, tree height, DBH, crown width

FIGURE 2: Road surface modelling feature data.

The specific algorithm steps are as follows (see Algorithm 2):

3.3. Three-Dimensional Lofting Technique

3.3.1. Linear Model Lofting Modeling. Curbs, guardrails, and other linearly dispersed targets have topological relationships that are vertically next to the road surface, with sections that are either rectangular or circular in the vertical direction and an overall direction that varies with the undulation of the road surface. In order to avoid the problem of manual interactive capture of wrong nodes leading to rework, the linear model lofting modeling technology based on characteristic lines and local monomers is studied to achieve rapid reconstruction of the target. This reconstruction method duplicates a 2D body object or monolithic model along a 3D reference line that can be set in different shapes on different road segments. The use of linear lofting technology can realize the rapid construction of a large number of linear models, which can better adapt to the data reconstruction and processing of bending and ramp positions. In this paper, the section of the curb linear target is used as the two-dimensional shape of lofting, and the outer edge of the road is used as the lofting reference path to automatically construct the target model. The edge cutting angle is automatically adjusted to make the model more realistic and ensure the seamless connection between the model and the road surface. The principle is shown in Figure 7.

The specific algorithm steps are as follows (see Algorithm 3):

3.3.2. Instance Modeling of the Single Model. For dotted ground objects such as street lights, sign street lamp and so on, firstly, the models of facilities, equipment and signs are constructed based on the target feature structure data. Then, batch replication and rotation are carried out based on the three-dimensional coordinates X, Y, Z and azimuth α.

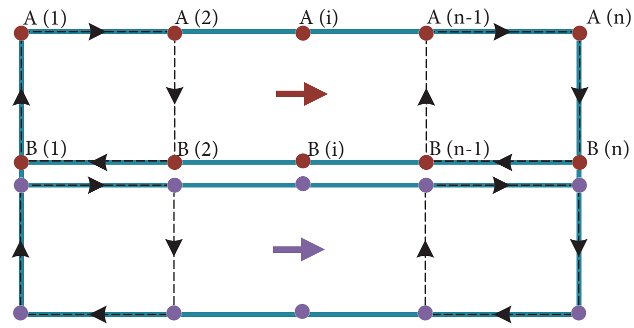


FIGURE 3: Schematic diagram of the principle of consecutive quadrilateral modeling.

Finally, the actual texture map is given to each sign, and the principle is shown in Figure 8.

The specific algorithm steps are as follows (see Algorithm 4):

4. Experiment and Analysis

4.1. Application of the Modeling Scene. In this paper, two sets of point cloud scanning data under different scenes obtained by vehicle mobile measurement system are used for experiments. The average point spacing of the experimental data is 5–10 cm. As shown in Figure 9, the point cloud data of road 1 contains 6312383 points; the road is relatively flat; as shown in Figure 10, the point cloud data of road 2 contains 4449024 points, which is a steep slope section, and the slope is about 4%, as shown in Figure 11, the point cloud data of road 3 contains 2591106 points, which are highway sections.

The road three-dimensional laser scanning data is imported into the multi-source point cloud data processing software for filtering and other preprocessing, and the required feature data are extracted from the high-precision and high-density vehicle laser point cloud data. Then based on 3Ds Max development platform, using the proposed method, the LOD3 level road model is automatically established, and two angles are selected to show the reconstruction effect. Experiments show that this method can quickly reconstruct a flat road scene, and it is also applicable to roads with a certain slope. The reconstruction rate is 100%. The results are shown in Figures 12–14.

In order to further verify the feasibility of this method, according to the detailed rules of road LOD model in Table 2, based on the road 1 point cloud data to extract structured feature data, using continuous quadrilateral pavement reconstruction, intersection topology structure relationship reconstruction and 3D release technology method, and the road target models at LOD1, LOD2 and LOD3 levels are established respectively. The models are compared under the wireframe model and the real model, as shown in Figure 15.

4.2. Modeling Quality Evaluation. In order to verify the accuracy of the model, the number of vertices, edges, polygons and triangles of the models with different levels of fineness are counted in the experiment, and the specific statistics are shown in Table 3. The LOD1 level model has the

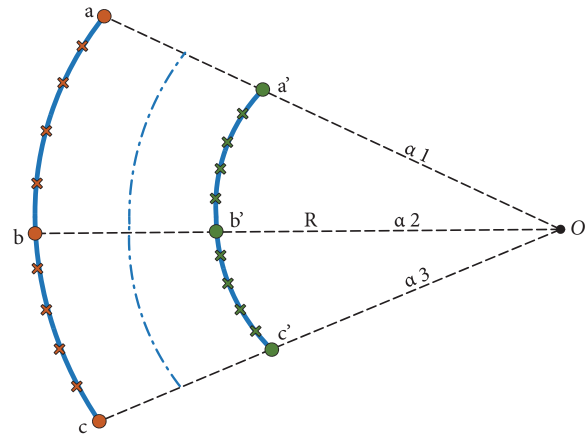


Figure 4: Schematic diagram of encryption at bends.

(1) Calculate the plane coordinates of the center O of the circle in which they are located according to the plane coordinates of the 3 centerline points a, b, and c.
(2) According to the formula of the distance between two points, the circle radius R value can be obtained.
(3) According to the coordinates of points a, b, c and the center of the circle O, three azimuth angles $\alpha 1$, $\alpha 2$, and $\alpha 3$ can be calculated.
(4) Based on this, a formula for calculating the coordinates of interpolated points can be derived. Let $f = \alpha 2 - \alpha 1$, to insert n points between a and b, then the azimuth angle $\alpha i = \alpha 2 + f \times (i/n)$, then the coordinates of the first interpolation point P_i are calculated as follows:

Algorithm 1: Curve smoothing algorithm.

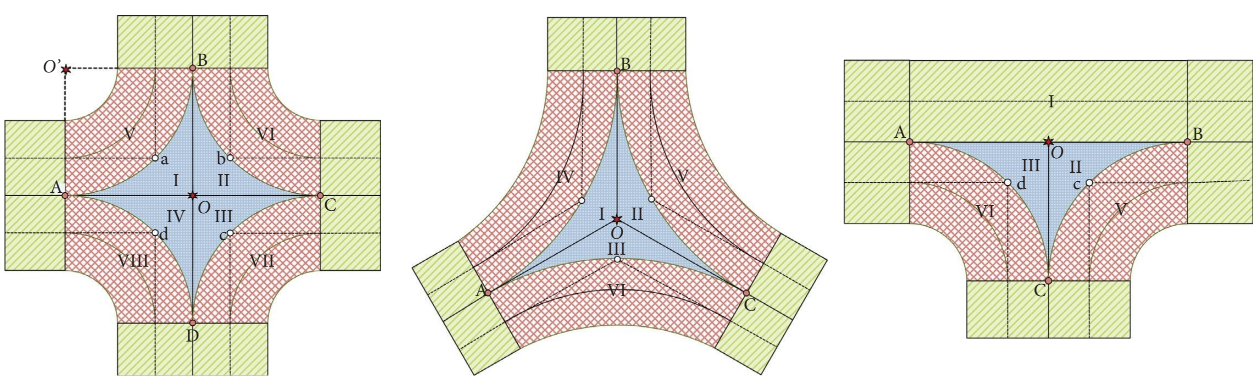
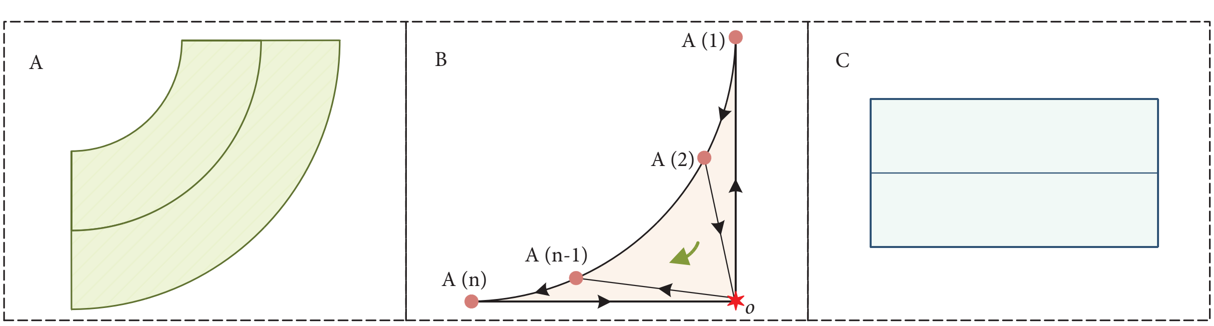
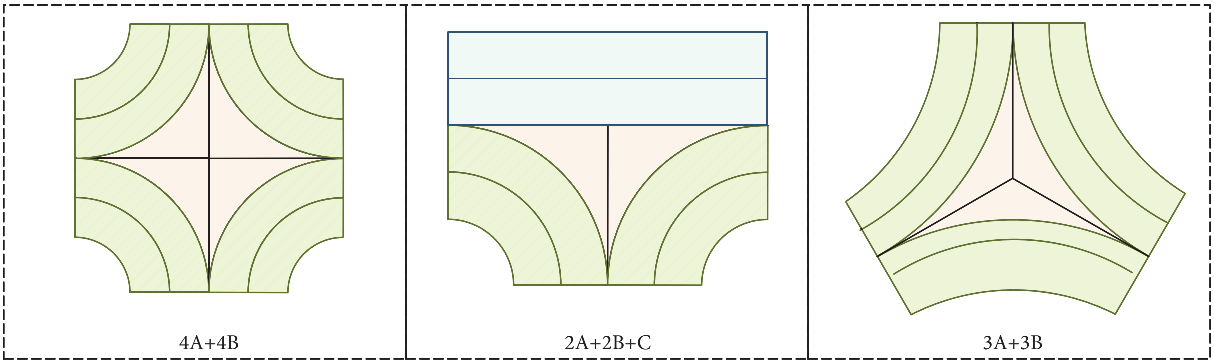


Figure 5: Three-dimensional linear design of intersection.



(a)

Figure 6: Continued.



(b)

Figure 6: Reconstruction of topological structure relationship. (a) Each component of the intersection. (b) Intersection structure.

Input: outer edge point coordinates $\{A\}$, center point coordinates O (x, y, z), texture material m
(1) all elements of array 1 were initialized and then the three-dimensional coordinates in $\{A\}$ were added to array1.
(2) for $i = 1$ to dot n do, $i = i + 1$.
(3) Initialize the spline line i, and take out nodes $A[i]$, $A[i+1]$, and O in turn.
(4) Close the spline line i to an editable poly i.
(5) Append all the graphics in {poly}, weld vertices.
(6) Select the sheet poly and give the material m.
Output: Outputs a triangular area model of the intersection

Algorithm 2: Intersection reconstruction algorithm.

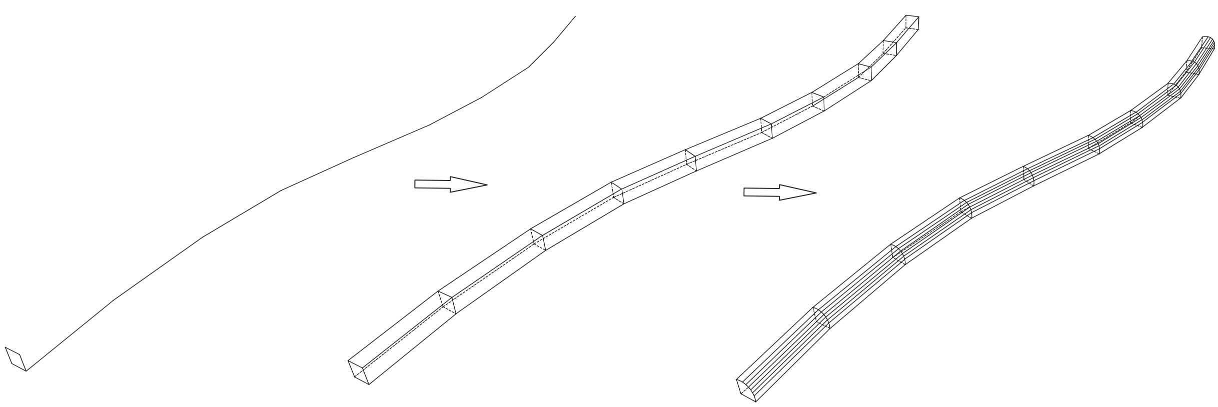


Figure 7: Schematic diagram of the three-dimensional release technique.

Input: length, width, route.
(1) Read length, width, output quadrilateral poly.
(2) Initialize the selection set $\{S\}$ and add route to $\{S\}$.
(3) Select $\{S\}$, staking according to poly.
Output: Outputs a 3D model of the linear facility.

Algorithm 3: Three-dimensional lofting algorithm.

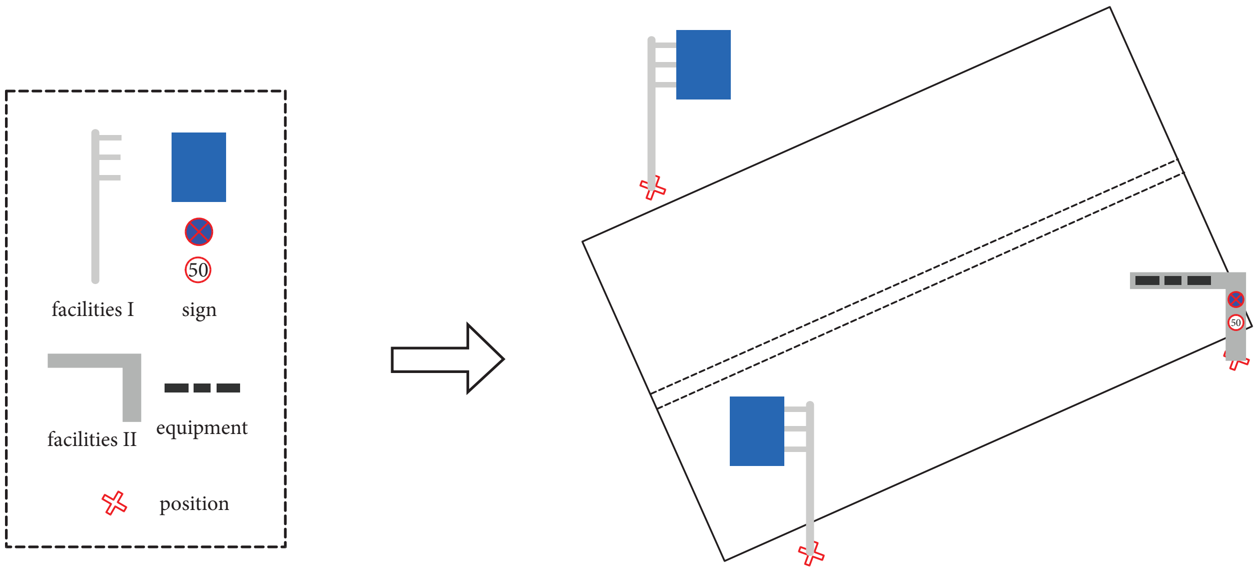


Figure 8: Instantiation principle of point facilities.

Input: bottom point coordinates and azimuth (x, y, z, α), template model *model*.
(1) Initialize the array *array1* and add the three-dimensional coordinates (x, y, z) in txt to *array1*; Initialize the array *array2* and add the azimuth α in txt to *array2*.
(2) for $i = 1$ to maximum dot do.
(3) Initialize the selection set {S} and add *model* to {S}.
(4) Copy {S} and rename *model*[i].
(5) Read the *array1*[i] three-dimensional coordinates according to the value of i and move *model*[i] to the *array*[i] position.
(6) Read the azimuth angle of *array2*[i] and select *model*[i] to rotate around the Z axis.
(7) Initialize the model collection {M} and add *model*[i] to the model collection {M}.
Output: Output model collection {M}.

Algorithm 4: Dot facility instantiation algorithm.

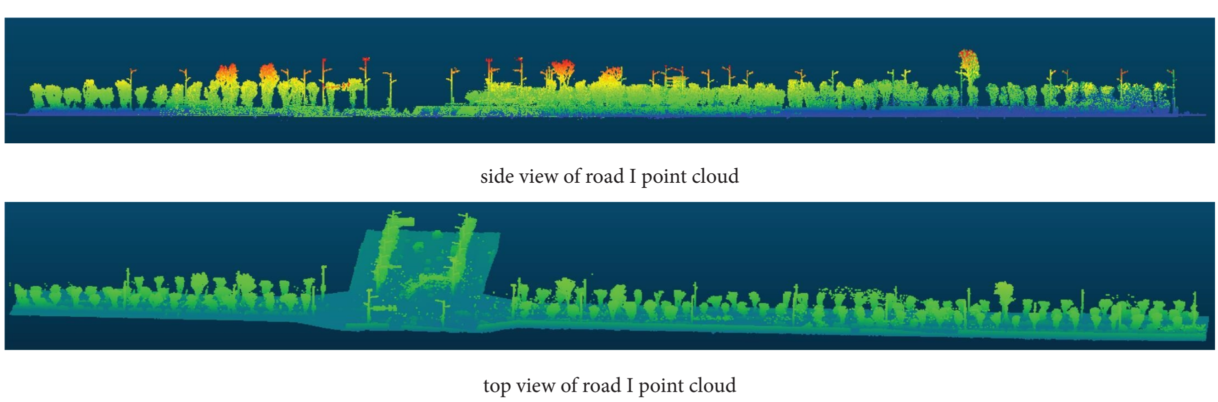
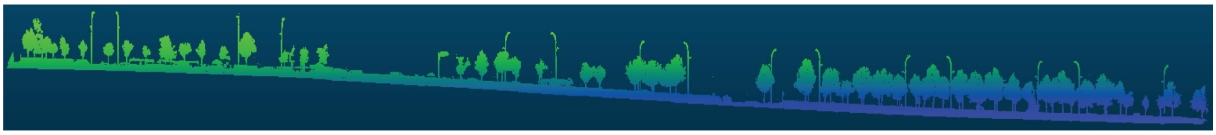


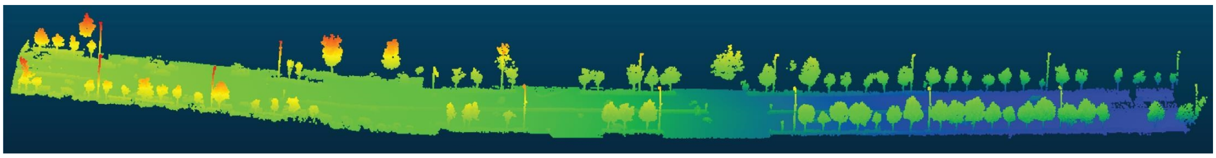
Figure 9: The point cloud data of road 1.

highest precision, LOD2 and LOD3 level model vertex number, edge number decreased in turn, precision is also reduced.

In addition to the detailed features of the statistical model, this paper uses the Hausdorff Distance Method [19] to calculate the similarity between the filtered point cloud data and the road 1 model at different levels. The statistical results are shown in Figure 16. After calculation, when the model fineness level is LOD3, the nearest point distance of 5818,123 data points in the point cloud of road 1 is between ±10 cm, accounting for 92.17% of the total number of point clouds. When the model fineness level is LOD2, the nearest

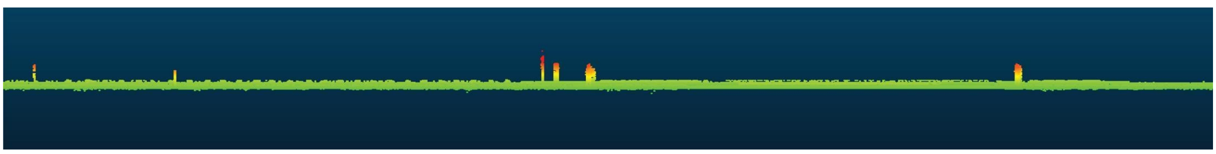


side view of road II point cloud

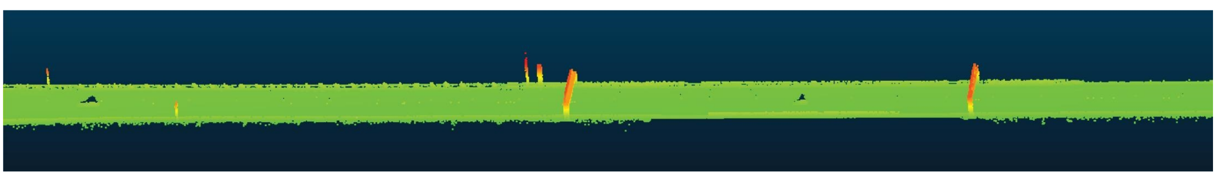


top view of road II point cloud

Figure 10: The point cloud data of road 2.



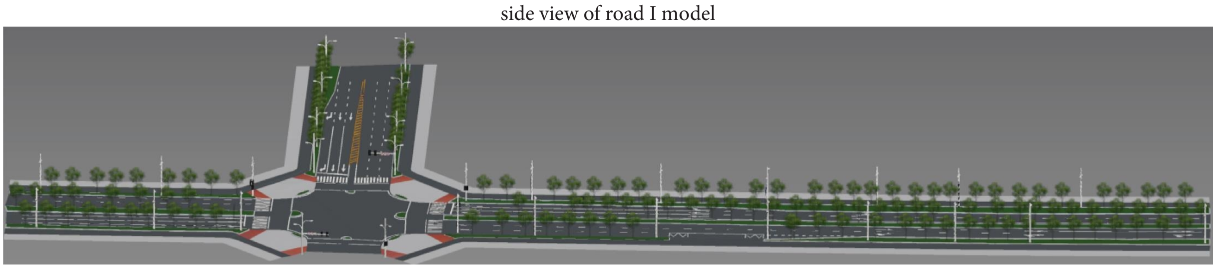
side view of road III point cloud



top view of road III point cloud

Figure 11: The point cloud data of road 3.

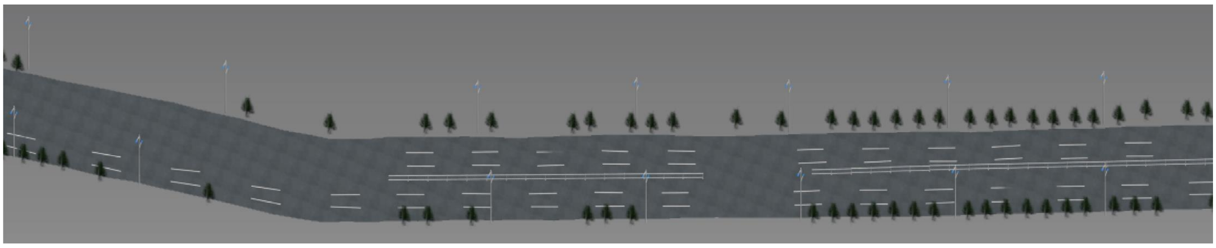
side view of road I model



top view of road I model

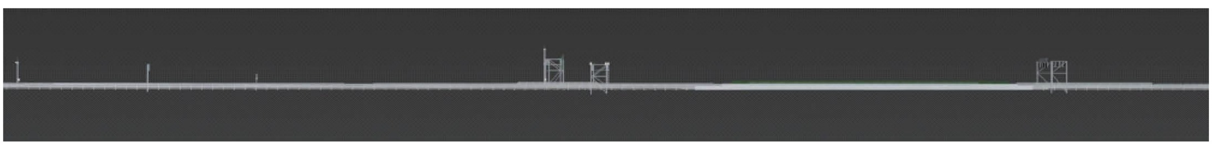
Figure 12: The model of road 1.

side view of road II model

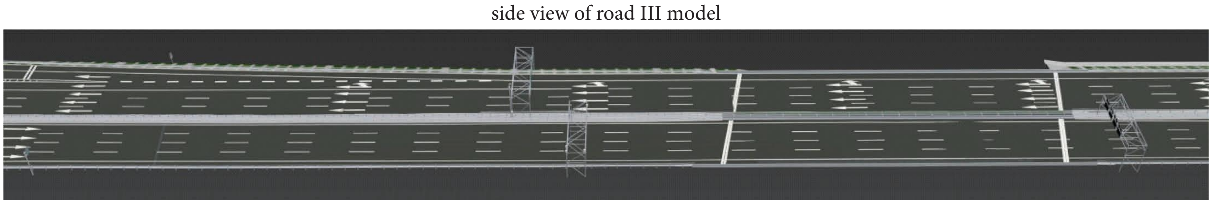


top view of road II model

Figure 13: The model of road 2.

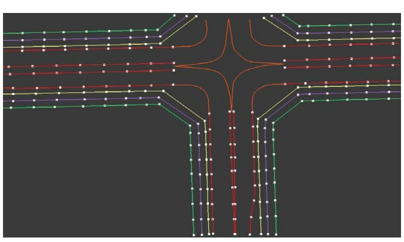


side view of road III model

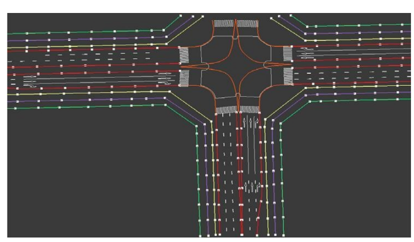


top view of road III model

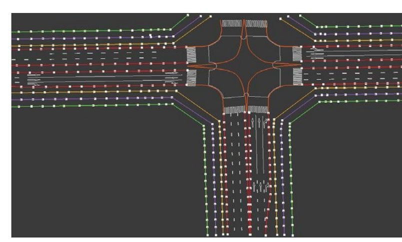
Figure 14: The model of road 3.



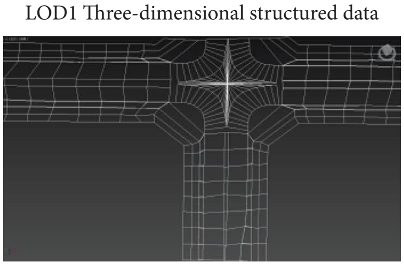
LOD1 Three-dimensional structured data



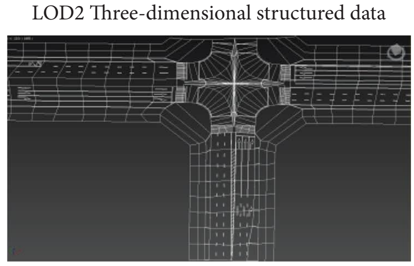
LOD2 Three-dimensional structured data



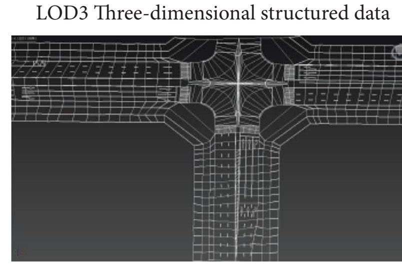
LOD3 Three-dimensional structured data



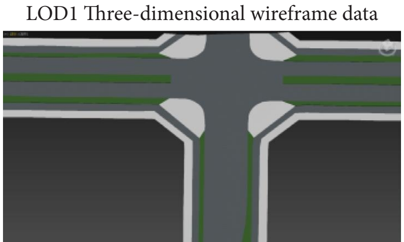
LOD1 Three-dimensional wireframe data



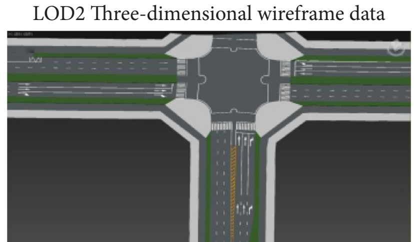
LOD2 Three-dimensional wireframe data



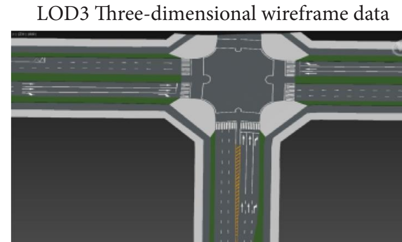
LOD3 Three-dimensional wireframe data



LOD1 Three-dimensional Real Model



LOD2 Three-dimensional Real Model



LOD3 Three-dimensional Real Model

Figure 15: The modeling process diagram road 1.

Table 3: Model details and feature statistics.

Grade of fineness	Number of vertex	Number of edges	Number of polygons	Number of triangles
LOD3	4325	4611	1182	2633
LOD2	3105	3395	879	2027
LOD1	1379	1492	427	850

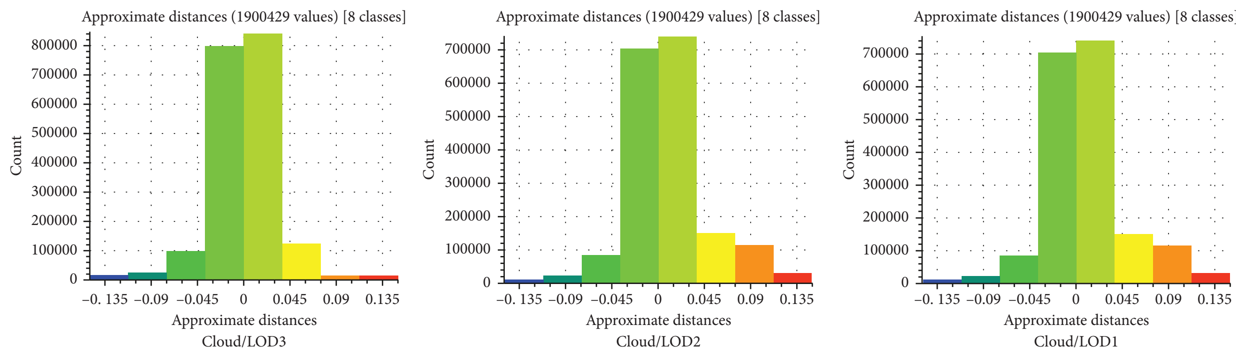


Figure 16: Nearest point distance statistical chart.

point distance of 5233597 data points is between ±10 cm, accounting for 82.91% of the point cloud number; when the model accuracy is LOD1, the nearest point distance of 4750068 data points is between ±10 cm, accounting for 75.25% of the number of point clouds. Overall, the nearest point distance between the three-level model and the point cloud data is basically controlled within ±10 cm. The LOD3 level model has the highest similarity with the point cloud data, and the LOD1 and LOD2 similarities decrease in turn.

5. Conclusions

In this paper, a fast 3D reverse modeling method for roads based on vehicle-borne laser scanning is proposed. This method is based on a variety of features of road 3D laser scanning data and designs a specific LOD model for road targets as the reconstruction details specification. With the help of point cloud processing software, the process from discrete point cloud data without semantic information to structured feature data is realized. Finally, the road 3D models with different levels of fineness are quickly established. Compared with the existing research, this paper applies the road data of vehicle laser scanning to the digital construction of traffic infrastructure and proposes a new LOD conceptual model for road targets, which is used for accurate expression, on-demand customization and personalized service applications. The three key modeling technologies proposed in this paper can achieve high-precision automatic reconstruction of road models, adapt to different types of road scenes, and provide a feasible technical route for realizing the full-element and full-cycle digitalization of traffic infrastructure. However, there are also some limitations, specifically the following: (1) The road intersection and reconstruction algorithm explored in this research only focuses on three simple and popular intersection types, without taking into account additional roads with complicated structures in depth. Furthermore, when the intersection and the pavement joint are shared, the junction locations must be shared, and the reconstruction data format is highly necessary. To address this issue, the terrain reconstruction algorithm can be included in future work, and the intersection road network model can be generated automatically based on the intersection feature structure data, improving reconstruction efficiency. (2) The instanced reconstruction algorithm of point targets examined in this research is only applicable to targets of the same specification for facilities and equipment, and grouping reconstruction is required for different types of facilities, which impacts modeling efficiency. To address this issue, we may incorporate the model size scaling technique into future research, allowing us to fully utilize the feature structure data, automatically scale the model, and restore a more realistic and detailed road scene.

Data Availability

Some necessary research data can be disclosed. If necessary, please send an e-mail to liurufei_2007@126.com.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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