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Research on Triangular Surface Reconstruction Algorithm Based on Point Cloud of Large Power Scene

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Abstract

With the advent of the information age, reverse engineering technology has become more and more widely used. Due to the uneven distribution and massiveness of the electric tower data set, the electric tower surface of the large-scale electric power scene is reconstructed. The point cloud data is first compressed, and the octree segmentation method and the radius neighborhood search algorithm are used for point cloud prediction. Processing, and finally using the triangulation algorithm to reconstruct the surface of the power equipment, and at the same time using Poisson reconstruction for comparison experiments. Experimental results show that the algorithm can efficiently and quickly restore the surface of the electrical tower, and the reconstruction effect is good.

Keywords

Point cloud reconstruction; Radius neighborhood search; Triangulation; Electric tower scene.

1. Introduction

With the rapid development of society, the country's demand for electricity continues to increase, and the power industry is developing more and more rapidly, with more ultra-high voltage lines, large substations, and T-shaped towers. What follows is a series of problems such as the management, inspection and maintenance of large-scale equipment. The traditional power management inspection method usually requires equipment survey and calculation on the ground, which is low in efficiency, poor in accuracy, high in strength, and possible. There are some potential survey hazards. Therefore, the point cloud data can be used to reconstruct the surface of the electrical tower, and the three-dimensional point cloud data can be used as a new data type to describe the object model of the electrical tower. The point cloud reconstruction work is mainly to restore and reconstruct the surface of the point cloud data of the electric tower, and obtain some important parameter information through computer processing, so as to conduct comprehensive management, information collection, data analysis, and information processing of the electric tower equipment Wait. The point cloud reconstruction method is used to manage the equipment of the electric tower with higher efficiency, convenient and simple operation, high precision, not affected by complex terrain, and saves a lot of manpower and material resources, which indirectly saves the cost of management and maintenance.

Therefore, the point cloud data of the electrical tower can be collected, and the point cloud data of the electrical tower belongs to the point cloud collection of a large scene, and the laser scanner can be used for scanning and collection processing, and finally the point cloud data set of the electrical tower can be obtained. After obtaining the data set of the electric tower, the data set can be preprocessed, compressed, and normal vectors can be calculated, and finally the surface reconstruction of the electric tower point cloud data set, as shown in Figure 1.

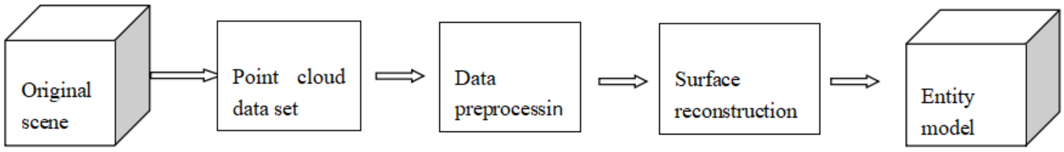

Figure 1. Flow chart of surface reconstruction

The point cloud reconstruction method is mainly divided into two parts: explicit surface reconstruction and implicit surface reconstruction. Explicit surface reconstruction can accurately describe the position information of the point cloud surface. Common reconstruction methods include: triangle surface reconstruction, B-spline surface reconstruction; The equation surface expresses the surface information of the object through the isosurface of the scalar function. Commonly used reconstruction methods include: implicit surface reconstruction based on Poisson equation, and implicit surface reconstruction based on radial basis function.

The topological relationship between the three-dimensional scattered data points corresponding to the multi-surface with holes in the space is more complicated. However, in the field of reverse engineering, the theory and method of direct triangulation of this kind of three-dimensional scattered data is not perfect. At present, the triangulation directly projected on the plane domain is generally divided into the main [1]. The point cloud data set of the electric tower belongs to the point cloud data of a large scene. The amount of data is large and because the structure of the electric tower is a narrow upper and a wide structure, the distribution of the point cloud is uneven, and the point cloud data in a part of the area is very dense. The point cloud data in another part of the area is very scarce, and the distance between the point clouds fluctuates relatively large. Therefore, the effect of the reconstruction process will be unsatisfactory, so a good reconstruction algorithm is very important.

Due to the particularity of the electric tower data set, the data distribution is not uniform, the distance between points is too large, it is difficult for the radial basis function to fit the isosurface of the implicit expression for reconstruction, and the Poisson reconstruction is more complicated. High, the algorithm implementation is also more complicated; secondly, because Poisson reconstruction is to integrate the entire surface of a closed 3D model, for a semi-closed point cloud model, using the Poisson method will produce excessive smoothness at the edge of the point cloud and cause blurring. , The effect is poor. Therefore, it is difficult to achieve by analyzing the implicit curved edge expression.

Moreover, the B-spline curve method is used for surface reconstruction, and the number of times to find a suitable reconstruction effect of the spline curve will be relatively high. Both the reconstruction effect and the efficiency are very low, so the B-spline surface reconstruction method is not suitable. Triangular reconstruction has the characteristics of good scalability, regular objects, and high requirements for uniform distribution. Therefore, triangular reconstruction is the most suitable reconstruction method. The 3D space point data is mapped to the 2D space, and the 2D plane triangulation algorithm is used for the 2D point data set to generate the plane triangle mesh, and then the 2D plane triangle mesh model is mapped to generate the corresponding 3D surface triangle The mesh model [1].

2. Point Cloud Preprocessing

2.1. Space Division Selection

Since the scanned electrical tower point cloud original data set is just a set of point cloud data in a disordered state and only contains three-dimensional coordinates and colors, and no other information, it is impossible to judge the initial state of the data set such as the density and normal vector, and the topological structure more complicated. Therefore, it is necessary to preprocess the point cloud data, and perform surface reconstruction on the point cloud data more efficiently and accurately.

There are mainly three methods for dividing the point cloud space, K-D tree method, octree method and bounding box method. The KD method needs to implement a recursive process, and the algorithm is responsible for the preprocessing of a large amount of data; the bounding box method is less efficient for unevenly distributed point clouds, so it is not suitable for spatial division of electric tower data sets; octree is a suitable method It manages the tree structure of unevenly distributed 3D data, and improves the efficiency of data timing. The octree is used to achieve massive spatial information storage and management without point clouds. The algorithm comparison is shown in Table 1.

Table 1. Comparison of space division algorithms

Search algorithm	Advantages	Disadvantages
K-D tree	Small storage space, high search efficiency	Tree update is relatively difficult
Bounding box	Simple programming and wide adaptability	Low efficiency for unevenly distributed point clouds
Octree	Simple algorithm and fixed decomposition method	Large memory

2.2. Octree Construction

The octree is used to describe the three-dimensional point cloud tree-like data structure. One node of the octree represents the volume element of a cube. Each node has eight child nodes, and each child node can perform encoding calculations, which greatly improves the computing efficiency. In addition, the tree structure of the octree can divide the space hierarchically and orderly.

Due to the uneven distribution of the electrical tower point cloud data set, when the octree is hierarchically divided, there will be some cases where there is no point cloud data in the cube. Continued recursive division may cause waste of resources and reduce efficiency. Therefore, it is necessary to The amount of point cloud data is calculated and analyzed. If the point cloud data in the cube is less than a certain threshold, there is no need to continue the recursive layering of the octree on the cube.

Octree segmentation process: set the maximum recursion depth, find the largest bounding box, create the first cube, throw the identity element into the cube without child nodes, and all the unit elements in the cube are borne by the eight-character cube If it is found that the unit element allocated by the word cube is not zero and is the same as the parent cube, the child cube stops dividing.

When performing point cloud preprocessing, first divide the bounding box, and divide it recursively according to the size of the largest bounding box of the analyzed point cloud data set. The size of the diagonal of the smallest bounding box is 2R, and R is the sphere of the search algorithm. radius. After the bounding box division is completed, the index value of the point cloud is calculated and encoded. At the same time, it is necessary to set the voxel resolution of the octree. The voxel resolution is the voxel size of the octree. The high resolution means that the minimum space of the octree is smaller. The compression quality can be improved but the compression rate will decrease.

The corresponding relationship between the point cloud coordinates P(x,y,z) and the index value index(a,b,c) is, where λ is the voxel resolution:

$$\begin{cases} a = \text{int}(\dfrac{x - x_{\min}}{\lambda}) \\ b = \text{int}(\dfrac{y - y_{\min}}{\lambda}) \\ c = \text{int}(\dfrac{z - z_{\min}}{\lambda}) \end{cases} \tag{1}$$

Its encoding can be expressed in binary:

$$\begin{cases} a = a_{n-1}2^{n-1} + a_{n-2}2^{n-2} + a_{n-3}2^{n-3} + \dots a_0 2^0 \\ b = b_{n-1}2^{n-1} + b_{n-2}2^{n-2} + b_{n-3}2^{n-3} + \dots b_0 2^0 \\ c = c_{n-1}2^{n-1} + c_{n-2}2^{n-2} + c_{n-3}2^{n-3} + \dots c_0 2^0 \end{cases} \tag{2}$$

2.3. Octree Compressed Point Cloud

Dense point cloud sets describe spatial point cloud data by storing additional information such as distance, color, normal vector, etc. Therefore, it takes up a considerable amount of storage space and resources, which leads to time-consuming and too dense points during surface reconstruction. The cloud reconstruction effect may not be smooth enough, so point cloud compression processing is required. The octree structure can efficiently merge and compress point cloud data from several input sources.

Modern sensors can capture very detailed large-area electrical tower data sets, which may contain large amounts of data, wide coverage of spatial coordinates, and large distances between data points, and there will be many redundant point cloud data. Therefore, the point cloud data set of the electric tower can be streamlined through the compression of the point cloud data. The compression process can save storage space and improve the efficiency of point cloud compression without losing the useful information on the surface of the object, and delete the redundant data. It can also avoid some invalid or redundant reconstruction information, and save the point cloud data on the surface of the object as simple as possible. Point cloud compression is based on the structural organization of the octree. It serializes the subdivision sequence bytes of the octree, and then uses detailed encoding or arithmetic encoding to perform entropy encoding.

The point resolution of the initial data set of the point cloud is required for compression. This variable determines the accuracy of the point coordinates during programming when the detail coding is performed. Due to the uneven distribution of the point cloud data inside each voxel in the electrical tower data set, if no detail coding is performed, only one point will be set inside the center of the voxel, and its attribute value will be the mean value of the points inside the voxel. A lot of detailed point cloud information is lost. Therefore, the program will be programmed using the detail coding method. The detail coding belongs to the division of the octree voxel. The point cloud data inside the voxel is analyzed, and the detail information of the point cloud inside the voxel is displayed through coding. Calculate the offset from the coordinates of each voxel to the lower left corner, and get along with the voxel resolution respectively, and finally get the encoding information of diffX, diffY, diffZ and the average value of these points, that is, the attribute encoding. If we perform detail encoding, we will encode the detail information of a point within a voxel, that is, the specific location and attributes of the encoded point. As shown in Figure 2.

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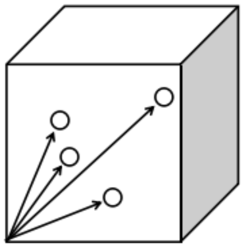

Figure 2. Schematic diagram of attribute coding

The octree resolution, multi-voxel grid downsampling, chroma resolution and other parameters can be configured to meet a variety of different configuration types of point cloud data, and finally get point cloud compression data sets with different effects. For example, low-resolution offline colorless point cloud compression, high-resolution online color point cloud compression, high-resolution offline colorless compression and a series of compression configuration methods.

3. Octree Radius Neighborhood Search

Neighbor search within the radius, the neighborhood is the collection of other points near a certain point in the spatial distance. The radius search algorithm can increase the search speed of the neighborhood and control the search range within a certain range of the center sphere. After setting the search point, use radius as the search range to search for the radius, save the Euclidean distance between each neighbor point and the search point, and save the set of points that meet the conditions into the set. The use of radius neighborhood search can facilitate the verification of the triangle reconstruction, the principle of maximum empty circle, and the radius neighborhood search can traverse all the points around the search point space, and the K proximity search may be lost in the space due to the K value constraint The best neighborhood point, the search range is not wide enough.

$$d(p,p_i) = \|p - p_i\| = \sqrt{\left(x_p - x_{p_i}\right)^2 + \left(y_p - y_{p_i}\right)^2 + \left(z_p - z_{p_i}\right)^2} \tag{3}$$

Step 1: Determine the number and the octree index value index (search) of the search point with search;

Step 2: Start the search in its cube bounding box with radius as the radius, save the index value index (neighbors) of each neighboring point, and the Euclidean distance of the neighboring point must be less than the search radius radius.

Step 3: Use the index value index (neighbors) of the neighbor point as the search point to search the neighborhood within the recursive radius. After each recursion, the index value index (neighbors) of the new neighbor point is covered to ensure that after each search is completed Updates to new neighborhood points.

Step 4: Stop the recursion when there is no new neighbor point in the neighbor point, and record the index value.

4. Point Cloud Triangulation Surface Reconstruction

Surface reconstruction based on triangulation takes the initial point cloud data according to a certain algorithm and finally obtains the triangular mesh. The pros and cons of the algorithm will directly determine the quality of the point cloud reconstruction, so it is very important to find a suitable triangulation algorithm.

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The realization idea of the triangulation algorithm for three-dimensional space surface is based on the two-dimensional space triangulation algorithm [3]. When using point cloud triangulation, the projection method needs to perform normal estimation and coordinate transformation between the projection points, which is computationally intensive and low in efficiency; secondly, the projection method will transform the three-dimensional coordinates of the space into two-dimensional plane points and into two-dimensional Triangular reconstruction is performed after the plane points, and finally the two-dimensional reconstructed surface is restored to three-dimensional space. In the restoration process, errors, voids, or unsatisfactory experimental results will be unavoidable. Therefore, it is not suitable to use the projection method to reconstruct the electrical tower data.

The point cloud data set of the electric tower is characterized by uneven distribution, uneven density of different spaces in the coordinate system, and the relatively large distance between the point cloud and the general point cloud data model, which is likely to cause the formation of holes. The reconstruction effect of triangulation is closely related to the density and quality of the point cloud. A data set with good density and quality can get a very ideal surface model. A series of problems such as holes will appear in the reconstruction model of a data set that is too sparse, and points that are too dense Cloud data will also affect reconstruction efficiency.

First construct an initial triangle, search according to certain algorithm rules based on the principle of maximum empty circle and the principle of minimum acute angle and maximum, find the most suitable neighbor points and connect them to expand the patch, and recurse continuously from the bottom to the top of the electric tower to finally get the whole electric tower The reconstruction of the triangular surface.

4.1. Principle of Maximum Empty Circle

The circumscribed circle of any triangle face will not contain other points, so there will be no long and narrow and intersecting triangles.

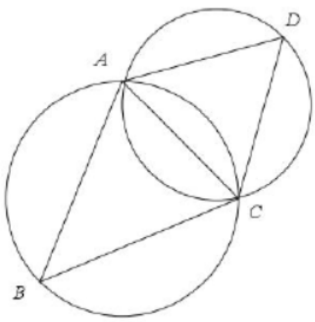

Figure 3. Principle of Maximum Empty Circle

4.2. Principle of Maximizing Minimum Angle

In order to maintain the best reconstruction effect, the most ideal reconstruction triangle is a regular triangle, which can reconstruct the surface of the object most uniformly, that is, the three corners of the triangle are close to each other. When two adjacent triangles form a quadrilateral with six corners, calculate the size of the internal angles separately; change the diagonal of the quadrilateral at the same time, recalculate the size of the six corners, if the size of the smallest angle is greater than the size before the diagonal is changed The size of the smallest angle can ensure that the principle of maximizing the angle of the smallest angle is satisfied at this time, and the reconstructed triangle has a higher quality.

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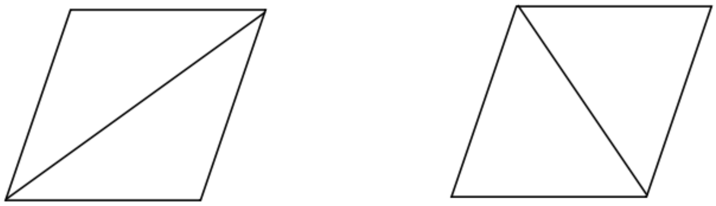

(a) Original quadrilateral (b) Exchange diagonal

Step 1: Construct the initial point of the initial triangle: Since the point cloud data shape of the electrical tower is relatively fixed, most of them are T-shaped electrical towers, so in the initial seed selection, the point cloud can be triangulated from the bottom of the electrical tower from top to bottom Extension.

For point cloud data (xi, yi, zi), the initial triangle ABC, point A selects the largest point in the x-axis direction, and the smallest point in the y-axis z-axis direction, so that the selected initial point A (xmax, ymin, zmin) at the bottom of the tower. Use the lowest end of the electrical tower to grow the area and complete the reconstruction of the entire point cloud data.

Step 2: Construct the initial edge: Calculate the point A to construct the initial triangle. Use point A as the search point to search for the nearest point B within the radius, and connect AB as the initial edge. That is, AB=min{ABi}, Bi is the i points of the neighborhood search within the radius.

Step 3: Find the best point: After constructing the initial edge, search for the radius neighborhood with the midpoint of AB as the center. The radius is half of AB. Put all the points within the radius into the list. The principle of maximizing the minimum angle and the principle of maximum empty circle find the most suitable point within the radius.

Step 4: Establish a triangle vertex list and edge list, and add the triangle vertex information and edge information to the table

Step 5: Repeat steps 3 and 4, and add the newly connected edges and newly generated triangles to their respective lists, and delete the generated edges until the list is empty.

5. Experimental Results and Analysis

In this experiment, a simulation experiment was performed on the point cloud data set in vs2019 and pcl1.9.1. The operating system is windows10, the main frequency is 2.2MHz, and the processor is i7-8750H. The simulation uses the data set as the electric tower data of the power grid, and the file type is a .pcd format file. This paper reconstructs the electric tower data set, compresses the point cloud data, and uses the radius proximity search and delaunary triangle reconstruction algorithm to reconstruct the electric tower data surface.

5.1. Point Cloud Compression

There are only two kinds of algorithm data sets used in this paper, the overall electric tower data set (T9-T10.pcd) and the partial electric tower data set (T9-T10_segment.pcd). The compressed effect diagram is shown in Figure 4 and Figure 5, and the compressed data parameters are shown in Table 2.

(1) Point cloud compression effect of T9-T10.pcd dataset:

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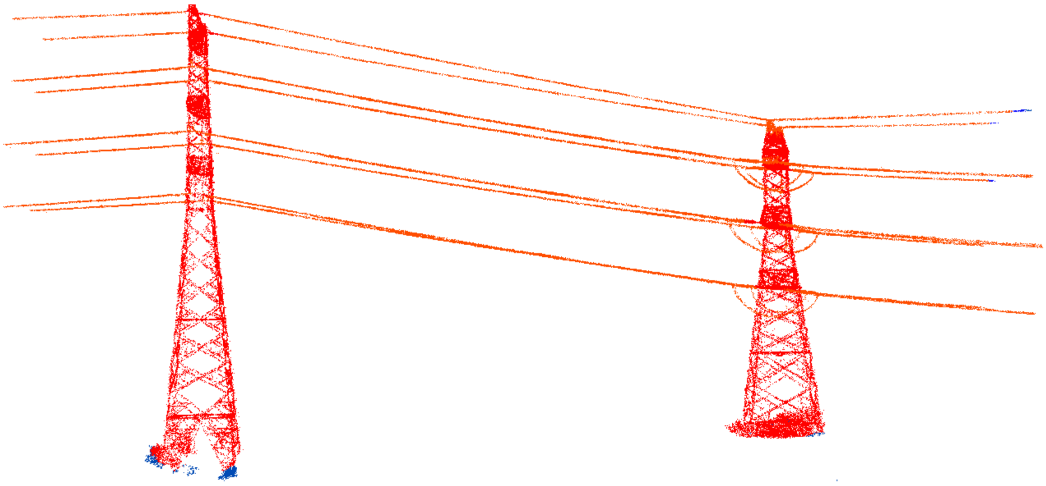


Figure 4. T9-T10.pcd data set compressed data

(2) Point cloud compression effect of T9-T10_segment.pcd data set

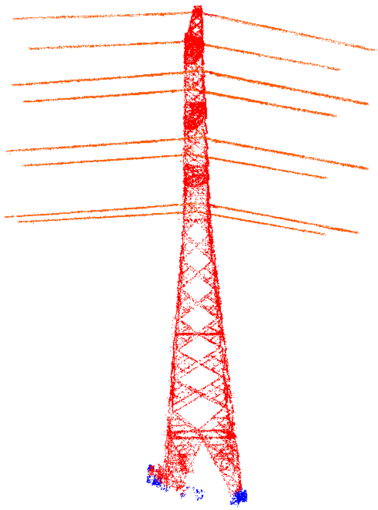


Figure 5. T9-T10_segment.pcd data set compression

Table 2. Data set compression table

Data set	Compress point cloud size(kb)	Uncompressed point cloud size(kb)	Total bytes per point(kb)	Total compression rate(%)	Compression ratio
T9-T10	450.074219	4057.359375	1.774846	11.092787	9.014868
T9-T10_segment	408.320313	4518.375000	1.445901	9.036883%	11.065762

5.2. Point Cloud Radius Neighborhood Search

In order to display the radius neighborhood search more clearly, we adjust the search radius range to 2, find the initial point as pioints[200000], set the color of the point cloud in the neighborhood to blue, and change the original data The color of the point cloud is all set to white. The experimental results are shown in Figure 6:

T9-T10.pcd dataset radius neighborhood search graph (partial)

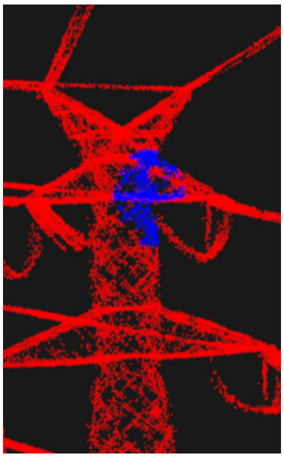


Figure 6. Schematic diagram of radius neighborhood search

Through experiments, the coordinates of the current point can be obtained as (604.95, 430.29, 38.7), and the number of neighbor points with radius 2 is 5168.

5.3. Surface Reconstruction Based on Triangulation

After the preprocessing of the data set and the neighborhood search, the surface reconstruction of the data set of the electrical tower is performed. The test data sets are T9-T10.pcd data set and T9-T10_segment.pcd data set.

(1) Comparative experiment of triangulation reconstruction and Poisson reconstruction of the T9-T10.pcd dataset

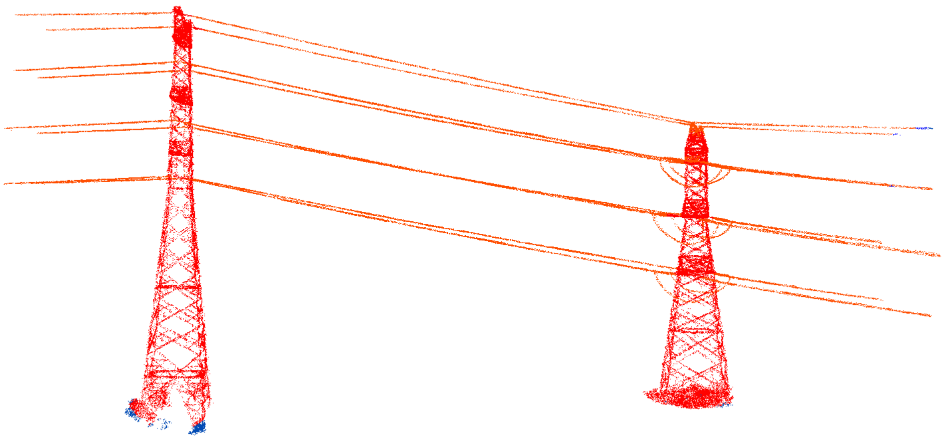


Figure 7. T9-T10.pcd original data set

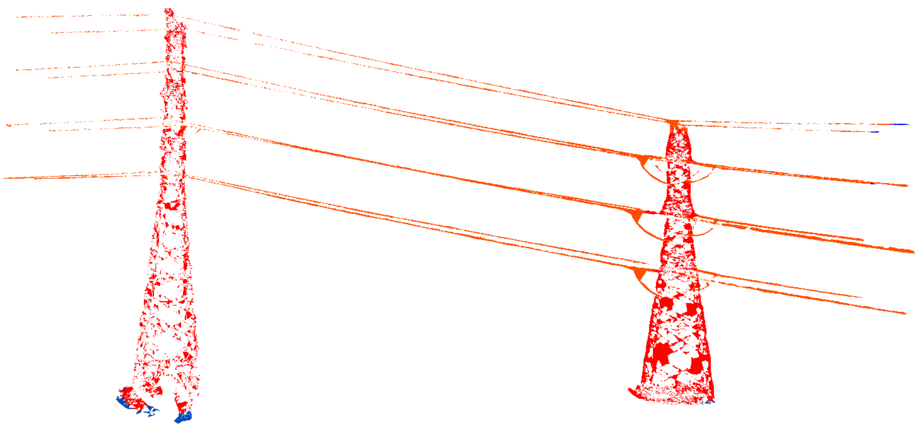


Figure 8. T9-T10.pcd triangulation reconstruction effect

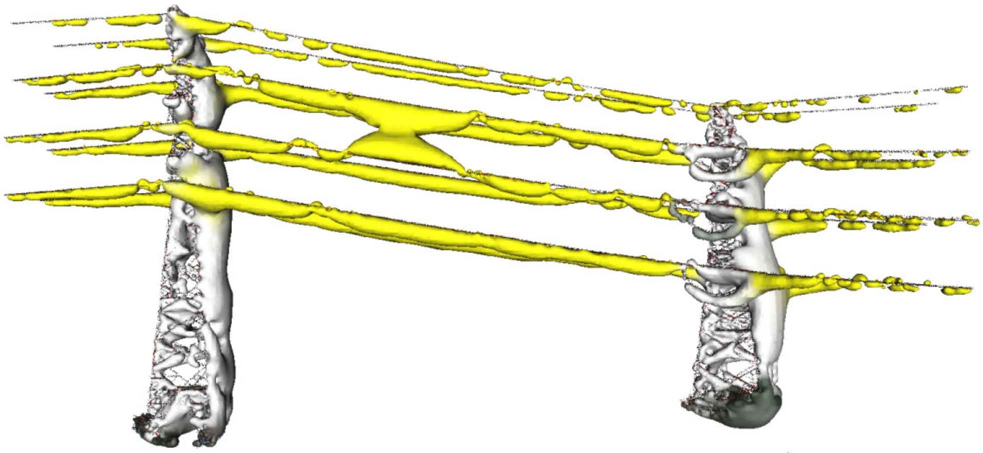


Figure 9. Poisson reconstruction effect of T9-T10.pcd

The data set of the entire electrical tower has a large amount of point cloud data, a wide coverage area and uneven density. After calculating the normal vector, the Poisson reconstruction is carried out using level 10 to reconstruct 737,888 triangles and 368,096 vertices. It is easy to generate bubbles and the effect of cable reconstruction. Very unsatisfactory; the reconstruction effect using the triangulation algorithm is ideal. You can see the overall structure of the electric tower reconstruction, the cable reconstruction effect is obvious, and there are no bubbles or holes.

(2) Triangulation reconstruction and Poisson reconstruction comparison experiment of T9-T10_segment.pcd dataset

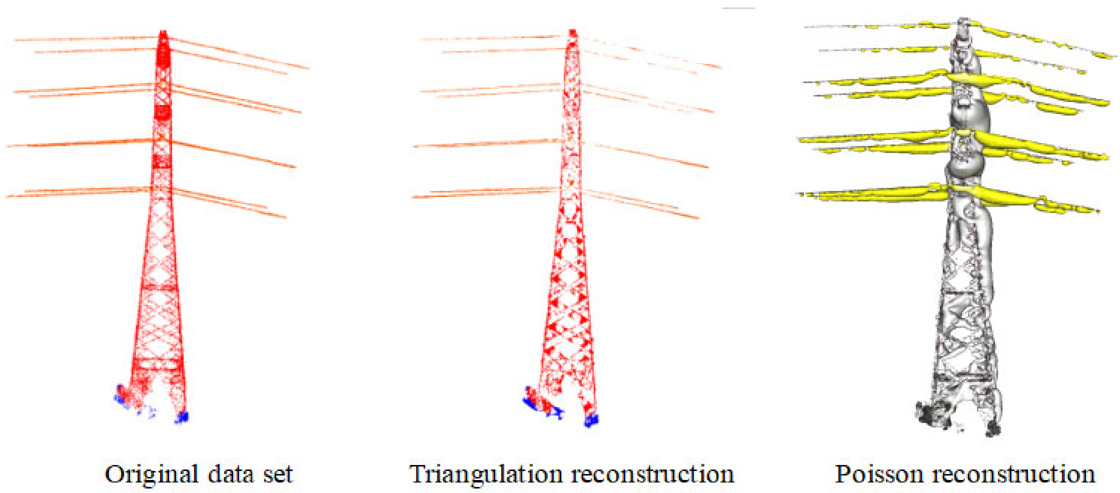
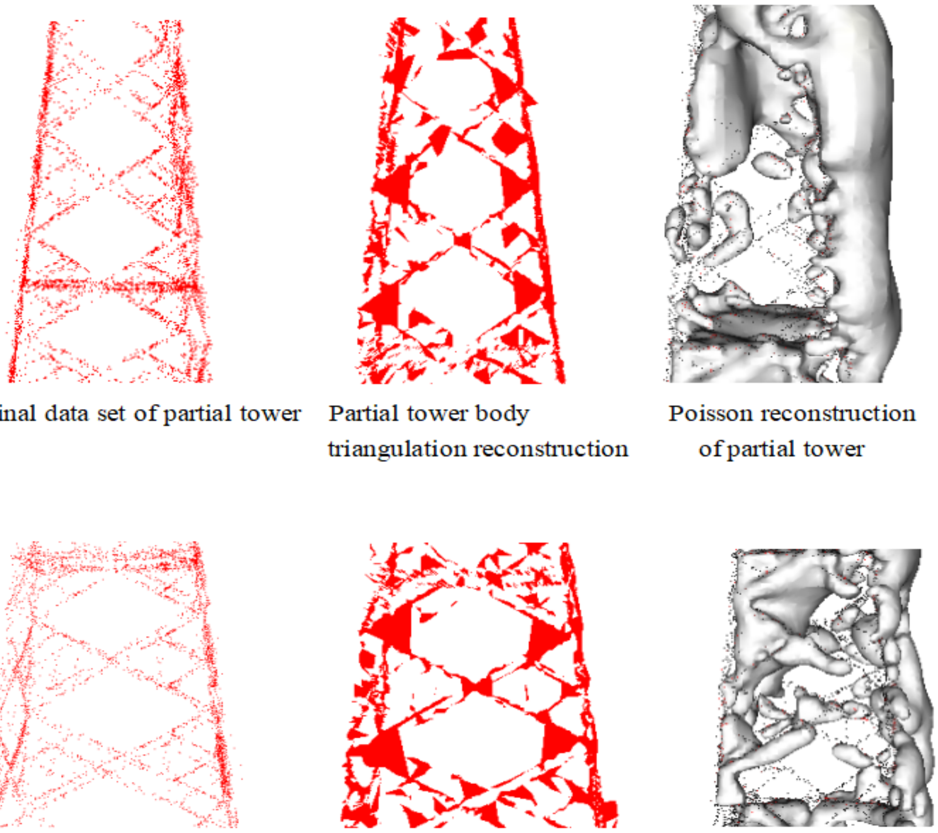


Figure 10. Comparison experiment between triangulation reconstruction and Poisson reconstruction

The Poisson reconstruction of a single electrical tower uses level 10 to perform Poisson reconstruction after calculating the normal vector, reconstructing 545,168 triangles, and 272,262 vertices. The reconstruction effect of a single electrical tower is still not very satisfactory, the surface distribution is uneven, and there are bubbles on the surface. The reconstruction effect of the cable is very poor, and the cable cannot be reconstructed; the triangulation reconstruction effect is ideal, and the surface structure of the electric tower can be restored well without the existence of voids and bubbles. Therefore, the effect of triangulation reconstruction is more ideal.



Original data set of partial tower | Partial tower body triangulation reconstruction | Poisson reconstruction of partial tower

Original data set of partial tower | Partial tower body triangulation reconstruction | Poisson reconstruction of partial tower

Figure 11. Partial comparison experiment between triangulation reconstruction and Poisson reconstruction

The partial Poisson reconstruction and partial triangulation reconstruction effect of a single electric tower. From the zoomed-in view, the Poisson reconstruction can not restore the original information of the electric tower very well. The loss of details is more serious and there are more bubbles; The reconstruction can reflect the reconstruction effect of the electric tower.

6. Conclusion

This paper performs surface reconstruction for large-scale power tower scene point cloud data. The algorithm in this paper analyzes the actual situation of the power tower, combines the characteristics of the power tower data for point cloud preprocessing, and divides the data space by an octree. During the surface reconstruction process Adopting the proximity search algorithm and the triangulation algorithm can quickly and efficiently perform surface reconstruction of large-scale power scenes. Compared with the traditional Poisson algorithm, the effect is much optimized, which is conducive to further analysis and processing of power scenes.

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