Power Tower extraction method under complex terrain in mountainous area based on Laser Point Cloud data

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Abstract. The accurate extraction and location of pole tower point cloud in massive laser point cloud data of transmission line is the basis of airborne laser LiDAR line inspection application. In view of the current complex mountain terrain pole tower point cloud extraction depends on manual intervention, low accuracy, low efficiency and so on. An automatic extraction method of line tower point cloud based on three-dimensional grid spatial distribution feature is proposed in this paper. Firstly, the three-dimensional grid of the original point cloud of the preprocessed transmission line is divided, and the spatial distribution characteristics of the point cloud in the statistical line corridor are analyzed (point cloud density, elevation histogram, terrain elevation distribution, ground object elevation distribution). In this way, the tower point cloud is extracted, and the least square space line fitting method is used to accurately locate the tower position, so as to realize the automatic extraction and accurate location of the tower point cloud. The extraction algorithm is verified by the transmission line laser point cloud data obtained from the actual inspection of a power grid company, and the integrity of the extracted tower point cloud data is 95%, and the average positioning error of the tower position is 9cm. The experimental results show that the method has good rapidity and accuracy.

1. Introduction
Airborne LiDAR has been widely used in transmission line location, engineering construction and safety inspection [1, 2]. It has the advantages of direct, efficient, high precision and all-weather data acquisition, as well as three-dimensional intuitive data representation, so that it has irreplaceable advantages in the application of traditional aerial survey methods in power grid [3,4]. In particular, the high frequency pulse of airborne LiDAR can partially penetrate the vegetation, obtain the topographic information under the high voltage line, and solve the problem of “blind area” of vegetation occlusion in artificial and traditional aerial survey. Moreover, because helicopters or unmanned aerial vehicles are less affected by weather and geographical environment, they can patrol transmission lines around the clock and in all regions, so the application of airborne LiDAR technology in power grid has attracted wide attention. Many people at home and abroad have carried out related research [5]. In the automatic positioning of transmission towers based on laser point clouds, there are only a few studies on automatic positioning of transmission towers from laser point clouds at home and abroad [6-12]. Among them, reference [9] proposes to use the distribution pattern of point cloud elevation histogram of local blocks to classify point clouds in order to distinguish ground, line, tower and other elements, but it is easy to be disturbed by complex objects in the actual environment. In reference [10], it is proposed that the ground points can be filtered first, and then the tower can be located by using the high density feature of the tower, but the filtering of ground points still depends on manual operation.
reference [11], it is proposed to identify and classify rods in laser point clouds by using the dimension characteristics of the neighborhood of point clouds, but this method is not suitable for large structures such as transmission towers. In reference [12], it is proposed to use the vehicle laser scanning data to distinguish the building and the rod by using the voxel model to detect the tightness of the block after filtering the ground, but this method can not automatically detect the transmission tower alone. The above methods make strict assumptions on the processed scenes, and can not be effectively extended to large-scale point cloud scenes. In this paper, weak assumptions are used to improve the versatility of the tower location algorithm.

Based on the three-dimensional grid spatial distribution characteristics of point clouds in transmission line corridors (point cloud density, elevation histogram, terrain elevation distribution, ground object elevation distribution), a method is proposed to automatically extract the transmission tower and accurately locate the tower position under the complex terrain in the mountain area directly from the original point cloud data.

2. Method

In this paper, by analyzing the characteristics of large slope and height difference in the power line pass area, the spatial distribution characteristics of point cloud three-dimensional grid in transmission line channel are analyzed. Based on the region growth algorithm and the least square space line fitting method, the automatic extraction and accurate location of tower point cloud are realized. The specific process is shown in figure 1.

Figure 1. Extraction and location process of Tower Point Cloud

2.1. Analysis of Spatial Distribution characteristics of Point Cloud in Line Channel

The spatial distribution characteristics of objects in the original cloud data of power line corridor were analyzed. When the point cloud was projected onto the horizontal plane, it could be found in the local range (a grid of a certain size). The point clouds in line corridors were mainly divided into three types: (1) only surface points (ground points, vegetation points, housing points, etc.). (2) mixing of surface points and power line points. (3) mixing of surface points and tower points. Regions 1, 2, and 3 in figure 2 represented the above three cases, respectively. In addition, there were also a small number of surface points, power line points and tower points mixed, but the number was small, usually did not
affected the crude extraction of tower point clouds and the calculation of tower position.

![Figure 2. Raw points cloud of transmission line corridor sample](image)

The spatial characteristics of the elevations of different ground objects were shown in figure 3. For the local range (such as 1m×1m, 2m×2m, etc.), if there were only surface points, they were usually continuously distributed in the elevation space. Only a few points with high vegetation areas form a certain interval, but the relative height of the point cloud in the grid was much smaller than that of the grid containing tower point cloud data. The power line was drape and its point clouds were discontiguous in elevation space, so multiple intervals of varying sizes were formed locally (with the exception of points with high vegetation risk extending near the power line). In the case of tower points, some of the points would have had a certain distance in the elevation space distribution, but their proportion to the whole grid data was small. Unless only the tower arm.

2.2. Tower point cloud extraction

Based on the analysis of the spatial distribution characteristics of the point cloud in the line channel, it is found that for the grid with only the surface points, the relative height of the point cloud is usually lower than that of the high voltage line tower and can be filtered by the relative height threshold. For grids with power line points and tower points, the relative elevation difference of point cloud data is small and can not be used as a factor to distinguish grid categories, but for a single grid data containing power lines, the sum of the spatial intervals is more than the sum of the data segments with point clouds, and most of the grids with power line points can be filtered out by using this feature. Then, on the basis of regular grid, the feature map based on LiDAR data (point cloud density, elevation histogram, terrain elevation distribution, ground object elevation distribution) is calculated, and the independent tower point cloud is extracted by feature threshold screening.

2.2.1. Grid partition

The key of grid division was to determine the size of the grid. The grid was too small, the number of point clouds distributed in elevation space was too small to carry out statistical analysis, and the grid containing tower point clouds would be filtered. The grid was too large, to a certain extent, it would increase the probability of continuity of grid elevation spatial distribution, but it would cause other points near the tower to be misdivided, affecting the subsequent tower location.

2.2.2. Calculation of Spatial characteristics of Tower Point Cloud

1) elevation histogram. For each grid data mentioned above, according to a certain hierarchical height from the lowest point, the number of points in each layer is counted from bottom to top, the elevation distribution histogram of each grid point is established, and the point-free cloud and continuous layers
are merged to calculate the interval height. Finally, the lowest elevation and the interval height meets the threshold requirements as the separation layer.

2) *density characteristics*. The density feature is an important basis for tower positioning, which takes a grid as a statistical unit, and the number of points (density) falling in the grid is the density feature.

3) *the distribution characteristics of topographic elevation*. The feature reflects the elevation distribution of the terrain undulation in the data. As the basic data of the distance feature, it can be used to remove the influence of the terrain undulation on the location of the tower. The elevation of the lowest point falling on all the points in the grid is calculated as the DEM feature.

4) *elevation distribution characteristics of ground features*. The feature reflects the elevation distribution of the ground objects in the data. As the basic data of the slope and distance image, it provides the necessary resolution information for the tower location, which can be obtained by calculating the highest elevation of all the points in the grid.

2.2.3. *Tower point cloud extraction.*

Using the above mesh features, the pole tower point cloud is extracted by feature threshold screening.

First, the point cloud data in the first case is removed, and a relative height threshold is set, which is filtered if the relative height of the grid is less than the threshold. Then, the point cloud in the second case is removed, and the ratio of the sum of the spatial distribution interval of each grid elevation to the relative height is counted according to step (2). If it is greater than the set threshold, it is filtered out.

2.3. *Tower position calculation*

The horizontal position of the tower is the intersection of the axis of symmetry, and the horizontal position of the tower is the intersection of the axis of symmetry, and the horizontal position of the tower is the intersection of the axis of symmetry. Intercept the middle part of each tower 5 m from the lowest point and 5 m from the highest point (to avoid the influence of a large number of ground points and power line and insulator points near the tower head). The position of the tower is determined by finding the center of each layer of point cloud data. The process is as follows:

2.3.1. *Determine the position of each floor tower*. Each layer of fixed line point clouds, insulator point clouds and other noise points were removed by using a denoising method based on two-dimensional grid. The rest was the tower point cloud on each layer. The position of each layer of the tower was determined by finding the maximum and minimum values of the projection points of each layer of point clouds on the horizontal plane in the x-axis and y-axis directions.

2.3.2. *Determine the final tower position*. Because the point cloud of each layer of tower might be missing (the acquisition of point cloud data was incomplete) or the denoising was not complete, the position of the calculated tower would be deviated. If it was obviously unreasonable to directly use the average value of the center of each layer as the position of the final tower, the least square fitting method would be used to determine the position of the tower [12]. The specific steps were as follows:

- Least square fitting theory of spatial straight line. The spatial linear equation was simplified to formula:
  \[
  \begin{align*}
  x &= x_0 + mz \\
  y &= y_0 + nz
  \end{align*}
  \]

- The parameters to be obtained were as follows: \(x_0, y_0, m, n\) written in the form of matrix (2):
  \[
  \begin{bmatrix}
  x \\
  y
  \end{bmatrix} = 
  \begin{bmatrix}
  z & 1 & 0 & 0 \\
  0 & 0 & 1 & z
  \end{bmatrix}
  \begin{bmatrix}
  m \\
  x_0 \\
  n \\
  y_0
  \end{bmatrix}
  \]

- The form of the error equation was rewritten as formula (3):
\[ V = B\hat{X} - L \]  
\[ B = \begin{bmatrix} z & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad L = \begin{bmatrix} x \\ y \end{bmatrix}, \quad \hat{X} = \begin{bmatrix} \hat{m} \\ \hat{x}_0 \\ \hat{n} \\ \hat{y}_0 \end{bmatrix}^T, \]

The formula (3) was simplified as follows:

\[ V = B\hat{X} - L \]  

- \( x_0, y_0, m, n \) could be obtained by solving the error equation.
- The normal vector \( \hat{n} \) of the spatial axis was calculated by the least square fitting formula mentioned above. Then the angle \( \beta \) between it and the normal vector \( \vec{e} = (0 \ 0 \ 1) \) of the horizontal plane was obtained. If it was less than the threshold \( \beta \), the average value of the coordinates of the points fitting the spatial line was used as the position of the tower. If the angle \( \beta \) was greater than the threshold \( \beta_0 \), the two farthest points from the line were removed and the angle \( \beta \) was obtained until the threshold \( \beta_0 \) was satisfied.

3. Experimental results and analysis

Based on the above methods, the point cloud data of a transmission line obtained by the helicopter LiDAR system of a power grid company are used to verify the application effect of this method. The length of the line is about 10 km, a total of 32 base towers. The integrity of the tower extraction, the deviation of the tower position calculation, and the time consuming are shown in Table 1.

| Number of towers | Number of extraction towers | Average integrity /% | Average position deviation /m | time-consuming /s |
|------------------|-----------------------------|----------------------|-------------------------------|-------------------|
| 32               | 32                          | 95                   | 0.09                          | 1.2               |

The experimental results show that the total time of the proposed method is about 1.2 s, and the average integrity of point cloud extraction from a single tower (the ratio of the number of point clouds extracted from the tower to the number of point clouds in the original data) is 95%. The extraction deviation of the central position of the tower (compared with the tower coordinates measured in the field) is 0.09m, which meets the application requirements of transmission line safety inspection in subsequent practical projects.

Fig. 3 shows the extraction result of the tower point cloud under the complex terrain in the mountainous area, and the black spot in the figure is the calculated center position of the tower. From the aspects of experimental effect, point cloud extraction integrity and positioning error, the results of tower extraction and location under complex terrain in mountainous area show that this method is robust to a certain extent.

(a) Original Point Cloud data of complex terrain in mountainous area
4. Conclusion
In this study, the tower and tower position information are extracted directly through the spatial distribution characteristics of airborne lidar point cloud data in transmission corridor, which simplifies the complicated intermediate process and realizes the fast and high precision positioning of tower.

Acknowledgments
This work was supported by the Financial support for Science and Technology projects of China Electric Power Construction Co., Ltd. No.DJ-ZDXM-2017-39 and The Major Special Projects of Guizhou Science and Technology Department, No. [2018]3007.

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