Research on High Voltage Power Line extraction based on Transmission Line Point Cloud characteristics and Model fitting

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Abstract—High-voltage power line digitization is one of the key contents of intelligent inspection of transmission line. Airborne LiDAR has obvious advantages in three-dimensional digital reconstruction of high-voltage power line. In this paper, a power line extraction algorithm for transmission line corridor based on LiDAR point cloud data is proposed. According to the distribution characteristics of point clouds in transmission line corridors, rough extraction of power lines is carried out. Noise points are eliminated by improved Hough and RANSAC parabola fitting method. Then the power lines are segmented horizontally and vertically. According to the vertical parabola model of a single power line and the straight line model of water surface, the complete power lines are extracted by model growth algorithm. Line point.
The experimental results show that the accuracy of the proposed algorithm is 99.6%.

1. INTRODUCTION
The rapid development of national economy has promoted the great expansion of high voltage transmission lines. Moreover, many lines often passed through a variety of complex geographical environment, which brought a lot of difficulties to the traditional manual inspection and maintenance[1]. This was a big problem, that was, how to monitor the operation status of transmission lines quickly, accurately and in real time was the power industry. In recent years, airborne LiDAR (Light Detection And Ranging) has developed rapidly in power line patrol. Its high efficiency and high precision three-dimensional real-time data acquisition makes it possible for transmission line digital management and intelligent inspection. This was the basis of intelligent inspection, that was, separating power line points from airborne point cloud data of transmission lines and digitizing them[2].

At present, there are many researches on power line extraction and 3D reconstruction for airborne LiDAR data, which mainly focus on the extraction of power line points, the division of power lines and the establishment of power line models [3,4]. The data was preprocessed by principal component analysis and projected to the two-dimensional plane, and then the iterative Hough transform was used to extract the power line points proposed by Melzer et al[5]. The ground points were filtered by elevation threshold segmentation filtering algorithm, and the method of extracting power line points based on two-dimensional Hough transform was proposed by Ye Lan et al[6]. The surface, vegetation and power line points were separated by triangular network encryption filtering and angle filtering based on the first echo information, and the power line modeling method based on hyperbolic cosine function were proposed by Yu Jie et al[7]. Based on the spatial distribution feature of point cloud, the method of
separating power line points, extracting power line position by Hough transform and realizing power line model by parabola local piecewise fitting was proposed by Yin Zenhui et al[8]. Based on the multi-echo characteristics of point clouds and the density difference of local point clouds, the non-power line point clouds were filtered, and then the power line points were detected by Hough transform with two-dimensional linear fitting. Finally, the method of using parabola equation to fit and reconstruct the three-dimensional model of power line was proposed by Han Wenjun et al[9]. The automatic filtering method of airborne LiDAR point cloud considering the characteristics of terrain fluctuation was adopted to filter most of the non-power line points, and then the method of detecting power line points by two-dimensional Hough transform was proposed by Chen Chi et al[10]. Based on the spatial distribution characteristics of point cloud, the power line and non-power line points were roughly separated, and the plane detection of power line was realized by RANSAC linear fitting. Finally, the method of combining the point cloud elevation statistics and the elevation distribution characteristics of the power line points in the same vertical plane to complete the split of the power line points was proposed by Wang Pinghua et al[11].

Although the above methods for extracting power line points from airborne LiDAR had achieved certain application results, it was found that these studies did not take into account the lost power line points after pretreatment. The linear detection through Hough transform could not eliminate the noise points on the same vertical plane as the power line points. This paper intended to extract the power line points from the spatial distribution characteristics of the point cloud data in the transmission corridor, and then based on the improved Hough transform and RANSAC (RANdom SAmple Consensus) parabola fitting method. The noise points which were not on the same vertical plane and on the same vertical plane were eliminated respectively. Finally, the straight line and parabola model of single power line was used to extract the power line points.

2. METHOD
In this paper, the extraction of power line points was based on the point cloud data of single-stage transmission corridor (the point cloud between two adjacent towers), which could be classified by the location of the tower. The extraction process was divided into rough extraction of power line point cloud based on spatial distribution features of point cloud, plane division of power line point based on improved Hough transform, and vertical surface division of power line point based on RANSAC parabola fitting. And based on the single-strand power line and parabola model growth fine extraction four steps, the process was shown in figure 1.

2.1. rough extraction of Power Line points based on Spatial Distribution Features of Point Cloud
By projecting the airborne LiDAR point clouds of the transmission corridor onto the horizontal plane, it could be found that in the local range, these point clouds could be divided into three types: surface points (ground, vegetation, house and other mixed points), surface and power line points mixed; The third type was the surface, tower point mixing (figure 2), there would also be a small number of surface points, power lines, tower point mixing, but the number was small, the impact on the follow-up process could be ignored.
Figure 1. Flow chart of powerline extraction

Regions 1, 2, and 3 in figure 2 represented the point cloud data for the above three types of cases, respectively. Figure 3 was a general map of the elevation distribution of the point clouds in the three types of cases (the statistical interval was 1 m), horizontal axis was the absolute elevation of each layer point cloud. The number of point clouds whose longitudinal axis was the corresponding layer. It can be seen that the elevation statistics of the local data of the mixture of surface points and power line points would have two parts of zero (as indicated by the arrow in the figure), which was the commonness of this kind of local data, so the rough extraction of power line points could be carried out based on this characteristic. The steps were as follows:

1) Grid partition

The grid statistics of the original point cloud data of the transmission corridor were carried out according to a certain size of grid. The key of Grid Partition was the setting of Grid size. If the grid was large, the continuity of the spatial distribution would be increased in the area with large terrain fluctuation in the statistical point cloud elevation distribution, and some of the power line points would be mistakenly regarded as noise, which would affect the establishment of the subsequent model. The grid was small, and some of the figure points would be used as power line points, which would affect the efficiency of subsequent linear detection. According to the characteristics of point cloud in transmission line corridor, the grid size was generally set to 2 to 4 m.

2) Statistics of elevation distribution of local data

The relative height of the grid with only surface points in the first category (the difference between the highest point and the lowest point elevation in the grid) was obviously lower than that of the second and third types, most of the first class grid points could be eliminated by setting the relative height threshold. Then follow step 2)

The dividing layer was obtained, the surface points and power line points in the second kind of grid were separated, and the points above the dividing layer were taken as power line points to obtain the rough extracted power line point cloud. There was no grid to meet the requirements of the relative height threshold, and all the points in the grid were eliminated.
2.2. Plane split of Power Line points based on improved Hough transform

The basic idea of line detection by Hough transform is to transform the straight line equation represented by point oblique or two points in XOY coordinate system into the representation method of polar coordinate system \((\rho, \theta)\) by using the duality of point and line. The \(\rho_0\) and \(\theta_0\) of a line are unique. The \(\rho_i\) and \(\theta_i\) of all lines passing through a certain point conform to a sine curve in the polar coordinate system, so the sinusoidal curves of \(\rho\) and \(\theta\) of each point on a line intersect at a point in the polar coordinate system. That is, the \(\rho_0\) and \(\theta_0\) of this line\[12\]. Based on this, the linear feature problem in the detected image could be transformed into the problem of finding similar points in polar coordinate system. The method was as follows:

1) Calculate the polar coordinates \((\rho_i, \theta_i)\) for each point. Due to the influence of insulators, drainage lines and point cloud quality, the power line points extracted from the spatial distribution characteristics of point clouds had more noise near the tower. In order to improve the efficiency and accuracy of the algorithm, the points at a certain distance near the tower were temporarily eliminated, and the \(\theta\) range of the horizontal projection line of the power line point cloud could be determined according to the position of the tower. However, it was not necessary to calculate the \(\theta_i\) and its corresponding \(\rho_i\) of all lines at each point, which reduced the amount of computation and saved the operation time and space, and the accuracy of the algorithm could be improved by increasing the angle resolution of \(\theta\).

2) Obtaining Point Cloud data in accordance with Linear characteristics.

In order to find the same (or similar) \(\rho\) and \(\theta\), we needed to solve four key problems. In: a) Hough transformation, the farther the point was from the coordinate origin \((0, 0)\), the more sensitive the \(\rho\) change was when the same angle \(\theta\) was transformed. In this way, it was necessary to reduce the angle change step (that was, increased the angle resolution) to improve the detection accuracy, but it would increase the amount of computation and reduce the efficiency of data processing. b) increasing the angle resolution could improve the linear detection accuracy, but if the \(\rho_i\) and \(\theta_i\) methods used in general image processing were the same\((\rho_i, \theta_i)\), accuracy was lower. c) the horizontal projection of the power line point cloud was not completely in the same straight line, and the \(\rho_i\) and \(\theta_i\) were not completely equal.
on the same straight line, so there was a certain error. d) High-voltage lines in transmission corridors were generally composed of multiple strands and should be taken into account in order to avoid omissions.

In order to control the sensitive problem of the variation of $\rho$ with $\theta$, the point cloud data could be translated to the coordinate origin as a whole. In order to solve the multi-strand power line problem, the cyclic method could be used to obtain the power line points that meet the requirements. Based on this, this paper used the method of RANSAC to obtain the adjacent points, the specific process was as follows:

a) The $(\rho_i, \theta_i)$ obtained in 1) is randomly selected as an interior point $(\rho_0, \theta_0)$, and the point error was used as its mathematical model.

b) Judge the distance between all other points and $(\rho_0, \theta_0)$, meet the threshold requirements was the local point.

c) The model was evaluated by the number of points in the local area and the accuracy of errors in all points. If the threshold requirement was satisfied, the model was the power line point.

d) Repeat the iteration a) ~ c) step k times, under the condition of satisfying the requirement of the error threshold in the point position, the optimal model with the largest number of local points was selected.

e) Repeat the iteration a) ~ d) step, until there was no power line point to meet the requirements, multiple power line point clouds could be obtained.

2.3. Vertical plane Segmentation of Power Line points based on RANSAC Parabola fitting

Through the above process, on the one hand, the noise point on the same vertical plane as the power line was eliminated, and on the other hand, the plane division of the power line point was realized, but the noise point which was on the same vertical plane as the power line was not dealt with accordingly. And the power line point on the same vertical plane was still a whole. Based on this, considering that the projection of the power line on its vertical plane was parabola, based on the RANSAC parabola fitting method, the process of extracting and dividing the power line points in the vertical direction was as follows:

1) The direction of the point cloud in each transmission corridor was not necessarily parallel to the coordinate axis. If the parabola model of the power line point on the vertical plane was required, the coordinate system should be rotated, and the angle of rotation should be calculated according to the position of the tower. The rotated point cloud data was projected onto the vertical plane to form a point set of transverse coordinates $t_i$ and longitudinal coordinates $z_i, (t, z), (i = 0, 1, ..., n)$ which was the number of point clouds remaining after the above process.

2) Three points were randomly selected as local points from the point set $(t_i, z_i)$, and the parabola model $z = at^2 + bt + c_i, i = 0, 1, 2, ..., k$ is established, $k$ was the number of iterations needed to calculate the optimal model.

3) It was determined whether the distance between other points in the point set and the parabola meet the threshold requirement. If so, this point was an internal point, that was, a point on the same parabola.

4) Through the number of local points and the least square fitting method, the error in the model was calculated and the rationality of the model was evaluated.

5) Repeated the above step 2) ~ 4) $k$ times, selected the parabola model with the largest number of points as the optimal model, and the detected internal point was a single power line point cloud.

6) In general, the power line had multiple layers, repeated iterative steps 2) ~ 5) until there was no optimal model, the split on the vertical plane of the power line point cloud could be realized.

2.4. Power Line Point Cloud extraction based on Linear and Parabolic Model growth

Through the above processing, the single-strand power line point cloud data was not complete, but the linear and parabola models of single-strand power line could be obtained. The model growth method was used to further extract the remaining power line points. The method was as follows.
1) The parabola equations of the straight line of the point cloud on the horizontal projection plane and the vertical plane of the point cloud were established, such as formula (1).

\[
\begin{align*}
  y &= ax + b \\
  z &= at^2 + bt + c
\end{align*}
\] 

(1)

2) The distance between each point in the unprocessed point cloud data and the single-strand power line model was judged respectively, and the power line point cloud was used to complete the fine extraction of the power line point cloud to meet the threshold requirements.

3. EXPERIMENT AND ANALYSIS

Taking the airborne LiDAR point cloud data of an EHV transmission corridor of State Grid as an example (figure 1 above), the effectiveness of the proposed method was verified. The point cloud data of the transmission corridor had two layers and four power lines, the plane distance between power lines was about 15m, the vertical distance was about 11m, the transmission line was about 395m long and 80m wide, the average point spacing was about 0.35m, and the number of point clouds was 3136840. Among them, there were 23436 power line points, the terrain was mountainous area, and the nearest figure of power line was about 10m.

According to the above point cloud characteristics, the grid size was 4m×2m and the hierarchical height was 1m to complete the rough extraction of power line point cloud. The effect was as shown in figure 4.

In order to avoid more noise near the tower affecting the efficiency and accuracy of Hough transform detection, the 10 m long point cloud near the tower was intercepted, and the angle step was set to 0.05°. The angle was 1° with θ and ρ was 1 m to complete the linear detection of Hough transform. Realizing the plane share of the power line (figure 5).

The RANSAC parabola method was used to judge the internal point, set the distance threshold between the point and the parabola was 2m, and realized the division of the power line on the vertical plane (figure 6). Finally, the fine extraction of power line points was completed by the growth of single-strand power line model (figure. 7).

Figure 4. Coarsely extracted points cloud of powerlines based on its spatial characteristices
This experiment takes a total of 2s, 23349 power line points were extracted, and the correct rate was 99.6%, which showed that this method could almost extract the complete power line points.

4. CONCLUSION
In this paper, a new method for fast extraction of power line points from airborne LiDAR point cloud data in transmission corridors was proposed, which had achieved good application results in terms of efficiency, accuracy and integrity. In particular, the problem of power line point loss in the process of preprocessing was solved. Through research and analysis, it was found that the algorithm in this paper needs to be further improved and optimized in the following aspects.

1) The point cloud data used in the experiment was very representative in the application of power grid engineering, but in practice, there might be some extreme cases, such as the absence of some power line point clouds in the point clouds of transmission corridors, or the large number of vegetation points, and so on. the rough extraction of power line points, and then affect the accuracy of power lines fitted by subsequent models were affected.

2) The projection of the power line point on the vertical plane was simply classified as a parabola model, and there would be some error for the point cloud of the power line in the long distance transmission corridor, which still needed to be further analyzed.

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