Power line extraction and analysis based on LiDAR

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ABSTRACT:

The traditional electrical power line inspection method has the disadvantages of high labor intensity, low efficiency and long cycle of re-inspection. Airborne LiDAR can quickly obtain the high-precision three-dimensional spatial information of transmission line, and the data which collected by it can make it possible to accurately detect the dangerous points.It is proposed to use the grid method to divide the data into multiple regions for the elevation histogram statistical method to obtain the power line point cloud at the complex mountainous terrain. In the non-ground point data, part of the vegetation point cloud is separated according to the point cloud dimension feature, and then the power line point and the pole point are distinguished according to the density characteristics of the point cloud so as to realize the point cloud classification of the transmission line corridor. On this basis, the power line safety distance detection is carried out on the power line points and vegetation points extracted by the classification, and the early warning analysis of the dangerous points of the transmission line tree barrier is completed. The experimental results show that the method can classify the acquired power line corridor point cloud and extract the complete power line, which effectively eliminates the hidden dangers and has certain practical significance.

1. INTRODUCTION

With the increasing number of high-voltage and long distance transmission lines, the vegetation in the corridor may destroy the infrastructure, and the vegetation inside the corridor needs to be effectively monitored[1].The traditional manual patrol inspection methods have many disadvantages, such as high labor intensity and low inspection efficiency. There are many important routes for crossing overhead transmission lines and there are many vital lines passing through complex geographical environment, and there are blind areas of patrol inspection that can not be reached by manual[2].At present, UAV patrol lines usually carry digital cameras, infrared cameras and other equipment to observe the passing lines. However, these methods are not accurate enough in space location, and the various data processing obtained is scattered and cumbersome. It is difficult to accurately determine the spatial distance between the corridor and the line. Therefore, the conventional detection method of transmission line can not meet the needs of the development of modern power grids. Overhead high-voltage transmission calls for scientific and efficient power line inspection method[3].

With the continuous development of remote sensing technology, laser radar has been widely used in inspection of transmission line with its unique advantages[4].High-frequency pulses emitted by airborne LiDAR can penetrate the vegetation to obtain terrain information under the high-voltage line and acquire point cloud data of the transmission line corridor with high efficiency and high precision[5].The point cloud classification of transmission line corridor based on laser point cloud is the basis of the early warning analysis of tree barrier risk by airborne

LiDAR. Domestic and foreign scholars have carry out a lot of research on the classification of the point cloud data. Yu Jie[6] used the filtering method to filter out the ground point and vegetation point, and fits a single power line according to the hyperbolic cosine function. However, the extraction results of the mixed region of trees and power lines will be relatively poor. Song Shuang[7] rasterized the point cloud data with uniform density and calculated the feature image. According to the characteristics of high density, large slope and great height difference in the laser point cloud, the pole and tower points were located and identified. However, there was a misclassification between the pole tower and the ground vegetation. Guo Bo et al[8]took the point as the basic unit ,constructed the geometric characteristic parameters which reflect the difference of ground object types, and used JointBoost classifier to classify point cloud data, but this method needs more feature extraction and classification processing time. Fan Shijun[9] decomposed the full waveform information of the full waveform airborne point cloud, then extractd the waveform feature parameters and the elevation features for classification. This method has higher requirements on the data source. At present, there are still some difficulties in quantifying the spatial morphological differences of objects by waveform information, such as the waveform difference is not obvious, and it is difficult to accurately classify.

The above-mentioned literature proposed a unique method for the classification of laser point cloud data in transmission line corridors, which can recognize and classify point cloud elements to a certain extent, but there are some problems such as misclassifications of partial key points or low efficiency. This paper first introduces the basic principle of airborne LiDAR,

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and then diagnoses the safety distance of the point cloud data of the transmission line in the difficult area of the mountain line. The transmission line corridor mainly includes transmission lines, transmission towers, forest vegetation and ground point cloud data. The grid method is used to divide the data into multiple regions, and the elevation histogram statistical method is used to obtain the non-ground point cloud, and the point cloud data of the transmission line is initially obtained for the complex mountainous terrain, In the non-ground point data, there are power line points, towers, and some vegetation points, which contain potential danger points. Power line points, tower points, and forest vegetation are separated from non-ground points according to the characteristics of point cloud dimension and density characteristics. The ground point cloud data is removed by the grid filtering method so as to realize the point cloud classification of the corridor. The extracted power line point block generation space node performs effective extraction and fitting of the power line. The safe distance detection of the classified power lines and vegetation point clouds is carried out, and the early warning analysis of the dangerous points of the transmission line tree barriers is completed by constructing the data structure of kd-tree. The experimental results show that the method can classify the acquired power line corridor point cloud, extract the complete power line, and use the information provided by the laser point cloud data to analyze and check the security risks, which has certain practical significance.

2. BASIC PRINCIPLES

Airborne LiDAR measurement system is a multi-sensor system which was consisted of the laser ranging system, the dynamic differential measurement system, the inertial measurement device, the imaging device and so on. Using a laser pulse rangefinder mounted on a UAV platform, a discrete laser pulse is transmitted through the air to the surface of the terrain or ground object, which is reflected back through the surface and received by the receiver, thereby accurately measuring the light pulse from the emission to the interval between reflections, given that the speed of light is known, the propagation time can be converted to distance, that is the mode of the vector is the distance between the transmitter and the ground laser foot measured by the laser ranging system[10]. Dynamic differential GNSS provides precise position information of the flying platform, and inertial measurement of single cloud (IMU) measures the attitude parameters of the flight platform in space, including roll angle, tilt angle and heading angle parameters.

The airborne lidar can measure the position of laser foot on the ground based on the principle of space geometric vector positioning: using inertial navigation system and encoder to obtain four azimuths of aircraft in flight $(\varphi, \omega, \kappa, \theta, s)$; The distance between the center of the laser scanner and the ground point is obtained by the laser scanner using dynamic differential DGPS to obtain the coordinates of the starting point, that is, the laser scanner center $O_s(X_s, Y_s, Z_s)$, so that the other end of the laser vector can be calculated. Three-dimensional coordinates of points $P(X, Y, Z)$. Figure 1 depicts the principle that the airborne lidar systems can calculate the position of a ground foot. The onboard lidar measurement system can record multiple reflections of the same pulse, such as a laser pulse hitting the top of a tree crown first, a part of which continues to hit the leaves or branches down, or continues to hit the ground down. So it will generate multiple return point records, which can completely collect all three-

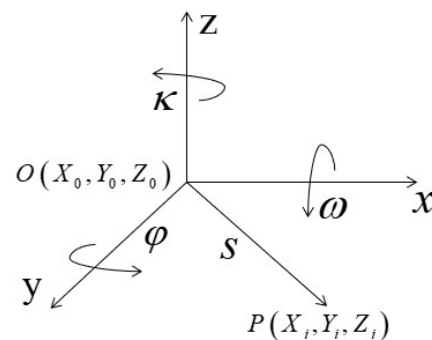dimensional information of features[11]. The calculation formula is as shown in formula (1).

Figure 1. Localization principle of LiDAR sysytem

$$
\begin{cases}
X_i = X_0 + \Delta X_i = X_0 + f_x(\varphi, \omega, \kappa, \theta, s) \\
Y_i = Y_0 + \Delta Y_i = Y_0 + f_y(\varphi, \omega, \kappa, \theta, s) \\
Z_i = Z_0 + \Delta Z_i = Z_0 + f_z(\varphi, \omega, \kappa, \theta, s)
\end{cases} \quad (1)
$$

3. POINT CLOUD CLASSIFICATION

3.1 The rough extraction of Power line

The extraction of power lines is a difficult point in point cloud classification. The airborne lidar measurement system can acquire a large number of laser point cloud data, including ground points, buildings, vegetation, rivers and other places, which often interfere with the extraction of power lines. In particular, a large number of ground laser point clouds affect the extraction speed of transmission lines. Therefore, ground point removal is first performed before detecting the power line. the traditional elevation histogram analysis method removes the ground point and initially extracts the power line point by setting an appropriate threshold Since the overhead distance of the high-voltage line is generally 15-50 m from the ground.

However, this method is only applicable to the area with flat terrain. For the problem that the terrain points and the power line are misidentified when the terrain is undulating, the whole gear data is taken as the overall processing strategy, and the power line point cloud cannot be distinguished.

The traditional method cannot distinguish the overlap of the power line point cloud elevation and the ground point cloud distribution elevation and the number of ground laser points obtained is much higher than the number of point clouds of the transmission line. For the problem that the terrain points and the power line are misidentified when the terrain is undulating in the mountainous area, the transmission line can be divided into multiple areas by the grid method, and the appropriate elevation threshold is set in each area to automatically eliminate the ground point, and Roughly extract non-ground points, non-ground points contain power line points, towers and some vegetation points. The algorithm works as follows:

First, determine the extent of the point cloud on the horizontal plane, and the horizontal space distribution is M:

$$\begin{cases} x_{\min} = \min(x) \\ x_{\max} = \max(x) \\ y_{\min} = \min(y) \\ y_{\max} = \max(y) \end{cases}$$

In the formula, (x, y) is the three-dimensional coordinate value of any point cloud.

Secondly, the axis with a longer length on the horizontal plane is divided into n spaces, each of which has a length d_x. That is, the point cloud space is divided into a plurality of small block cuboids, as shown in Equation 2.

$$\begin{cases} d = \max(x_{\max} - x_{\min}, y_{\max} - y_{\min}) \\ n = d / d_x + 1 \end{cases} \qquad (2)$$

Finally, set the elevation threshold to divide the point cloud data in each area into upper and lower parts. The upper part is the initial extracted power line point and the lower part is the ground point.

3.2 The accurate extraction of Power line

The preliminary extracted power line point cloud data also includes the power pole tower and part of the vegetation point cloud data. This paper uses the dimension feature based method to eliminate the vegetation point[12]. The vegetation points are automatically filtered out by using the dimension features according to the spatial geometric characteristics of the non-ground points obtained after filtering. According to the characteristics of the power pole point cloud on the vertical projection plane in the transmission line, the density of the point cloud of the power tower is much larger than the density of the power line point cloud to extract the tower point. Firstly, the optimal neighborhood radius of each laser point and its corresponding eigenvalues and eigenvectors are calculated according to the neighborhood size adaptive method, and then the dimension features are defined according to the eigenvalue $\lambda 1$、 $\lambda 2$、 $\lambda 3 (\lambda 1 \geq \lambda 2 \geq \lambda 3)$:

$$(a_{1D}, a_{2D}, a_{3D}) = \left(\frac{\sqrt{\lambda_1} - \sqrt{\lambda_2}}{\sqrt{\lambda_1}}, \frac{\sqrt{\lambda_2} - \sqrt{\lambda_3}}{\sqrt{\lambda_1}}, \frac{\sqrt{\lambda_3}}{\sqrt{\lambda_1}}, \right) \qquad (3)$$

In the formula, $a_{1D} + a_{2D} + a_{3D} = 1$。

The vegetation points appear as spherical targets in the point cloud space, and the eigenvalues in the three directions of x, y and z are relatively close. The electric tower point appears as a rod-shaped target in the point cloud space. The eigenvalues in one direction are relatively large, and the eigenvalues in the other two directions are relatively small and relatively close. The power line points also appear as rod-shaped targets in the point cloud space. Therefore, only the rod-shaped target can be selected to filter out the vegetation points. The dimension feature distribution map is shown in Figure 2.
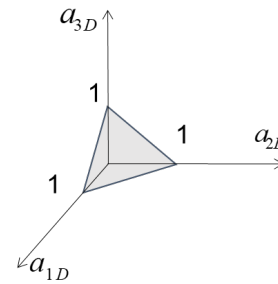

Figure2. The map of dimension feature value distribution

and the density of the adjacent two points is relatively small. The overall laser point cloud density statistical method is used to separate the tower[13] After eliminating the vegetation point cloud data, the point cloud density of the tower is relatively large. It is necessary to count it on the direction of the transmission line in order to accurately calculate the point cloud density of the tower.

Firstly, the general trend of the power line is judged according to the horizontal distribution space. Then, the grid area division method using the power line rough extraction is divided into n intervals, and the number of point clouds in each interval is counted in the vertical plane where the power line is located.

The position of the tower is obtained by judging the extreme point of the change in the density of the laser foot. The power line point cloud data is extracted by distinguishing the vegetation points and the tower points by using the dimensional feature and the density statistical method. There are many researches on filtering the ground points in the airborne laser scanning data by filtering method. In this paper, the classical TIN triangular filtering is used to filter out the ground point cloud in the aspect of terrain filtering.

4. HAZARD POINT DETECTION

The safety distance analysis of transmission line is the core of power line safety detection. The "Operation Regulations for Overhead Transmission Lines" requires that the line inspection to ensure that the distance from the power line to the corridor with various features meets the safety distance requirements. By analysing and calculating the distance between the power line and other corridors such as buildings, vegetation, the location of dangerous points is located, and the distance is determined accurately to determine the type of dangerous points, providing accurate information for the power line patrol personnel to facilitate timely line maintenance. It is effectively cleaned up the hidden terrain dangerous topographic objects under the power line, and ensuring that the power line is in a safe state for a long time[14].However, at present, the main method of power line ranging in China is artificial ground visual judgment or laser rangefinder measurement. In some areas, the UAV is gradually equipped with a high-definition camera to take photos and manually judge dangerous points by the images. However, there are very few methods for detecting the safe distance using the laser point cloud. Using the LiDAR point cloud data to explore and analyze the safe distance of the power line can effectively detect the safe distance of the power line by carrying on the lidar with the unmanned aerial vehicle (UAV) and using the point cloud data of the LiDAR.

The detection of the dangerous points in the transmission line corridor is mainly to judge the distance between the ground objects and the wires in the corridor of the power transmission line by manual or automatic method, and compare with the

standard safety distance to locate dangerous objects that do not meet the safety distance requirements. In order to clean up the hidden dangers in time. The project is a 220kV transmission line UAV laser scanning inspection where was located in the mountainous area, the trees grow more lush, no buildings. When the overhead transmission line needs to maintain a certain safe distance from the vegetation. Generally, the high-span design is adopted. For the transmission line without the high-span design, the trees cannot be planted in the corridor. The area of the trees must be felled. UAV is equipped with the laser radar to perform the inspection for acquiring the point cloud of the transmission line corridor, and the tree line is safely detected for the transmission line. The laser point cloud data is used to accurately measure whether the distance from the corridor to the wire meets the safe operation requirements. The safety distance between conductors and trees is shown in Table 1.

Table 1. The safety distance of Wire and vegetation

Nominal voltage U/kV	220	330	500	750
vertical dimension d/m	4. 5	5. 5	7. 0	8. 5
clearance distance s/m	4. 0	5. 0	7. 0	8. 5

The UAV is equipped with laser LiDAR for inspection to obtain the point cloud of the transmission line corridor, and the power line point cloud and vegetation point cloud data extracted by the classification are used to perform the tree barrier safety distance detection. The amount of vegetation point cloud data is large due to the dense vegetation in the mountains, which greatly increases the workload of detection and calculation. In this paper, the spatial index data structure based on kd-tree is used to divide the vegetation data point set in three-dimensional space. The power line point is set as the search point, and the vegetation point is searched. A sphere model is built to search for the vegetation point cloud by traversing the point cloud of the transmission line.If no dangerous points are detected, search for nearest neighbor vegetation points and analyze potential danger points. Determine whether the distance from the ground corridor to the wire meets the requirements for safe operation.

5. DATA PROCESSING AND ANALYSIS

The effectiveness and reliability of the proposed method are verified by field data collection in the field. The Dangjiang M600 PRO drone is equipped with the AS-100 multi-platform mobile laser radar system for laser point cloud scanning. The scope of the inspection line is located in the mountainous area, the slope changes greatly, and the vegetation coverage rate is high. The AS-100 multi-platform mobile lidar system is equipped with approximately 300,000 measurement points per second for accurate 3D reconstruction of complex environments and geometries for data acquisition. The original laser point cloud data, image data, IMU data and GNSS data can be obtained through the field data collection, The collected data can not be directly browsed and processed by point cloud in software. The raw data differential GPS data post-processing, the determination of the combined attitude of INS and GPS, the time synchronization processing of different sensors, the eccentricity correction, and the coordinate transformation are required to obtain the three-dimensional coordinates of the transmission line[15].

The process of generating complete laser point cloud data with three-dimensional spatial information from the original point cloud is very complicated and needs to be completed by multiple spatial coordinate system conversion calculations. The coordinate system conversion process includes four parts: first, converting the instantaneous scanning coordinate system to the scanning reference coordinate system; secondly, converting the scanning reference coordinate system to the IMU reference coordinate system; again, converting the IMU reference coordinate system to the navigation coordinate system; Finally, the navigation coordinate system is converted to the CGCS2000 coordinate system. The navigation solution data is processed with the original point cloud data, that is, the spatial three-dimensional coordinate information of each measurement point (X, Y, Z) can be obtained, and the transmission line point cloud model with the spatial three-dimensional coordinates is as shown in Figure 3 .
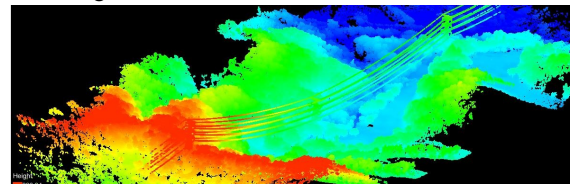

Figure 3. The cloud model of Transmission line point

5.1 Transmission line classification

The LiDAR data provides three-dimensional spatial information on the surface of the transmission line corridor, as well as information on elevation, density, color, and echo intensity.

The point cloud data of the transmission line is divided into multiple regions according to the characteristics of the transmission corridor. The reasonable segmentation threshold is set separately and divided into upper and lower parts, which are displayed in different colors. The result after segmentation is shown in Figure 3..

For the extracted non-ground point cloud data, the points and tower points are eliminated according to the point cloud dimension characteristics and density characteristics. The classical TIN triangle filtering method is used for filtering for the transmission line topography. The point cloud classification is shown in Figure 5, and Figure 6 is a top view.

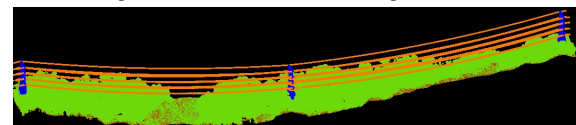Figure 4. Grid elevation segmentation

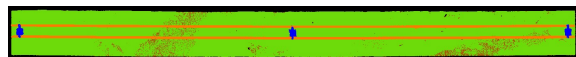Figure 5. The classification of transmission line point

Figure 6. The top view of point cloud classification

5.2 Dangerous point detection

According to the requirements of the power industry standards and specifications for safety distance, based on the classified laser point cloud data, the distance between the transmission line and the ground and trees is automatically calculated automatically, and the tree barrier distance detection and analysis is performed on the experimental line. The tree-pointed

safety distance detection is performed directly on the classified point cloud. The transmission line detection is shown in Figure 8, and the red dots represent dangerous points.
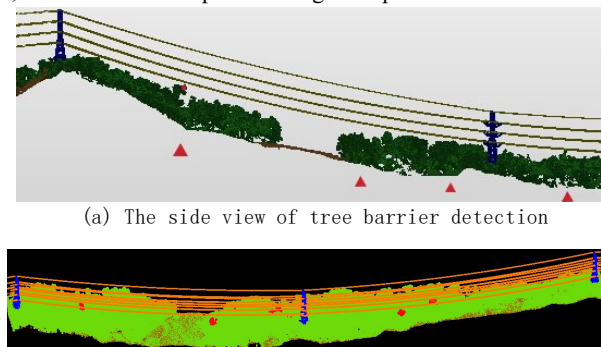
(a) The side view of tree barrier detection

(b) Tree barrier detection

Figure 8. The detection of tree barrier safety distance

6. CONCLUSION

This paper takes high-voltage transmission lines as the research object, and carries out high-altitude operations by using laser radar for drones, and conducts power line inspection based on airborne laser radar. The power line point cloud is preliminarily extracted by the grid partitioning based elevation histogram statistical segmentation method based on the analysis of the spatial distribution characteristics of the airborne lidar point cloud data in the mountainous transmission corridor. The power line points, tower points and vegetation points are accurately extracted based on the dimensional characteristics and density characteristics of the point cloud. The classical TIN triangle filtering method is adopted in the terrain filtering to realize the point cloud classification of the power line corridor. The data structure of kd-tree is used to construct the sphere search model, and the safe distance detection of the dangerous points of the tree barrier is realized for the power line points and vegetation points extracted by classification.

It is verified that the high-precision, high-resolution laser radar measurement technology can achieve high-precision three-dimensional information on the surface through the laser point cloud acquisition, classification processing, and dangerous point inspection. It can well overcome the defects in the power line inspection, and quickly obtain the spatial information of the terrain surface, characteristic features and line facilities of the high-precision power line corridor. It can greatly reduce the power line budget, reduce labor intensity and save Working time, improve work efficiency. Airborne laser radar technology will gradually become popular in power line security and survey design, and play an increasingly important role. At present, there are still some problems: the massive point cloud data brings inconvenience to the classification processing of the late point cloud, and there are problems of low efficiency and misclassification of power line point cloud and insulator point cloud data. The future development direction is to optimize the processing of point cloud classification algorithm. The artificial intelligence point cloud classification algorithm further enhances the data processing capability, improves the working efficiency for the subsequent power line inspection, saves the internal data processing time, and has strong practicability and stability.

REFERENCES

Lai X D, Dai D C, Zheng M. 2014: Research on three-dimensional reconstruction of power line based on LiDAR point cloud data [J]. Journal of Remote Sensing, 18(6): 1223-1229.

Zhang R H, Lin Y. 2015:Research on Key Technologies of Beach Surveying and Mapping Based on Airborne Lidar[J]. Surveying and Mapping Engineering.24 (01): 33-35.

Zheng J R. 2013: Application of Tianbao Trimble Harrier 68i Airborne LiDAR system in Smart Grid [J].Surveying and Mapping Bulletin, (01): 119-120.

Guo T, Shen P, Shi L.2018:Study on the method of Fast Positioning of High Voltage Tower with Airborne LiDAR [J]. Remote Sensing Technology and applications, 33(03): 530-535.

Zheng Y M, He Y R, Yu J W.2017:Measurement and analysis of multifunctional wind tunnel construction with laser point cloud[J]. Surveying and Mapping Science, 42(11):171-176.

Yu J, Mu C, Feng Y M.2011: Research on the method of extracting power lines from airborne LiDAR point cloud data [J]. Journal of Wuhan University (Information Science Edition). 36 (11): 1275-1279.

Peng X Y, Song S, Qian J J.2017: Extraction algorithm of tower position for UAV laser scanning operation [J].Power grid technology, 41 (11): 3670-3677.

GUO B, HUANG X F, ZHANG F.2015:Classification of airborne laser scanning data using JointBoost[J]. 2015.ISPRS Journal of Photogrammetry and Remote Sensing. (100): 71– 83.

Fan S J, Zhang A W, Hu X, Sun Weidong.2013: Airborne Laser Full Waveform Point Cloud Data Classification Method Based on Random Forest [J]. China Laser,.40 (09): 221-227.

Liu Z J, Liang J, Zhang J X. 2014: Fast extraction of airborne LiDAR data transmission lines based on spatial domain segmentation[J]. Journal of Remote Sensing, 18 (01): 61-76.

Sui Li C, Zhang Y B, Zhang S. 2011: Airborne LiDAR point cloud data filtering based on progressive triangulation network [J]. Journal of Wuhan University (Information Science Edition). 36 (10): 1159-1163.

Yang B S, Dong Z, Wei Z, Fang L.2013: A Method for Extracting Complex Building Facades from Vehicle Laser Scanning Data[J].Acta Geochimica Sinica.42(03):411-417.

LIU Z J, LIANG J, ZHANG J X.2014: Fast extraction of airborne LiDAR data transmission lines based on spatial domain segmentation[J]. Journal of Remote Sensing.18(01):61-76.

Wang H P, Xia S B, Tan H W.2015: Key Technologies of Airborne Laser Point Cloud Data Processing in Power Line Inspection[J]. Geospatial Information, 13(05): 59-62+8

Yu K J. 2015: Applied Research on Three-dimensional Lidar Measurement Technology for Transmission Lines [D]. Beijing: North China Electric Power University.22-4.