*, [1]Zhengdong Li
[1] Feiran Wang
[1] Geng Han
[1] Zilong Hou
[1] Xinyang Guo

Study on Real-Time Spatial Distance Acquisition Method of Transmission Line Based on Laser Point Cloud and Image Monitoring

Journal of Electrical Systems

Abstract: - This paper introduces the principle of safety distance diagnosis of transmission lines by using airborne LiDAR detection technology. This project intends to realize the effective segmentation of ground objects and non-ground objects through the point cloud automatic filtering technology considering the surface fluctuation characteristics. Then, this paper realizes the initial recognition of ground objects based on spatial dimension information. Then this paper extracts the ground object information based on the image data with high precision. The 3D nodes of transmission lines are obtained by Hough transform and block centroid algorithm, and the floor features are extracted by area growth algorithm. The plant feature is extracted by using plant vertex and boundary point. The distance between the power line and the surrounding objects can be measured, and the elevation of the wire and the surrounding environment can be judged accordingly. The algorithm is tested by using the observation data of unmanned airborne LiDAR, and the simulation results show that the proposed method is feasible. Through the identification of buildings, plants and other objects along the line, the harm degree of them on the power line is judged and the effective treatment is carried out. This ensures the safe operation of transmission lines.

Keywords: UAV; Airborne Laser Scanning; Transmission Line Corridor; Safe Distance; Intelligent Diagnosis.

I. INTRODUCTION

In the power grid, the distance of transmission lines is long, the coverage is wide, and the requirements for safety and reliability are high. Due to the impact of trees, buildings and other targets in the power line corridor, it has caused a huge safety risk, so how to timely find and eliminate the defect of "insufficient safety spacing" has become a key work in the current power system operation. However, due to a variety of objective factors, this type of failure often cannot be found or found not, tree barrier discharge or damage to external factors, may cause short circuit, power failure and other accidents, more serious will lead to wildfires[1]. Aerial laser scanning (ALS) is a new detection method that combines laser scanning and position orientation (POS) in recent years, which can quickly and accurately obtain the 3D spatial position of ground and ground objects, and has gradually developed into an important data acquisition method. Lidar technology has been well used in the survey and design of domestic power system, but its application in the inspection of power system is still in the exploratory stage. In the current power system, in the inspection experiment of manned and unmanned helicopters, the inspection platform is mostly equipped with conventional observation means such as infrared thermal imaging and telephoto camera to monitor the path [2]. The Central China Power system adopts the satellite image acquisition method to collect the multi-view image of the transmission line. In power system, through real-time acquisition of visible optical image of power cable, 3D image of target surface is obtained by computer vision technology, so as to complete the sag measurement of wire. The 3D LiDAR detection method can solve the shortcomings of the existing LIDAR-based inspection methods in spatial position, which can not accurately determine the distance between the traverse corridor and the transmission line [3]. Aerial Lidar scans to accurately capture the three-dimensional position of power cables and nearby terrain features. Subsequent processing will involve the automatic identification of power lines and then the calculation of gaps between those lines and any adjacent topographic features, facilitating a comprehensive assessment of power line safety margins[4]. This system is expected to significantly reduce resource requirements, including labor and material inputs, by improving the ability to automatically identify power lines and surrounding terrain in aerial liDAR scans, aimed at determining the vertical distance between power lines and nearby features[5]. By monitoring buildings, vegetation and other landmarks near power lines, the system will determine if a specified safety threshold has occurred, alerting utility companies to potential hazards. These interventions are critical to maintaining the integrity and reliable functioning of the power infrastructure.

[1] State Grid Jibei Electric Power Co. LTD. UHV Branch, Bei Jing 102488, China
*Corresponding Author: Zhengdong Li

II. Safety spacing diagnosis of transmission lines in aviation point cloud

According to the relevant provisions of DL/T741-2001 "Regulations for the Operation of overhead ", the spacing between the transmission line and various objects in the line gallery in the power system should meet the allowable safety spacing. The safety spacing inspection of the line gallery is to measure the spacing between the ground objects such as trees, houses, and crossings and the transmission line in the various pipeline corridors to ensure their safety [6]. According to the requirements of operation specifications, laser point cloud is usually divided into vegetation, buildings, ground surface, toured towers, transmission lines and other categories. Under natural conditions, the harmful objects of transmission line channels are mostly trees. A new detection method for transmission lines, buildings and vegetation in aerial LiDAR images is proposed.

A. Automatic extraction of transmission lines in aviation point cloud

The transmission lines in the transmission line point cloud data are extracted into the following steps:

1) The projection of the wire on the horizontal plane is a line, and the two lines are parallel to each other, and the horizontal direction of the wire is projected onto the wire by using two-dimensional Hough conversion. The x coordinates and y coordinates of the remaining wires are converted into two dimensional Hough in XOY plane in order to obtain more line equations [7]. The linear formula above is used to calculate the main direction of the transmission lines, and the lines with a large Angle to the main lines are excluded.

2) The transmission line points are discontinuous points on the XOY projection plane, and the transmission lines are separated by a certain distance. The Hough transformation can find many line segments with similar slopes, and their intercepts are also concentrated in some areas. By fitting the axis of the wire, the linear formula of the center line of the wire on the XOY plane is obtained, and the calculation formula is given.

3) Using the obtained midline formula of the wire on the XOY plane, the laser spot on each wire is calculated in reverse; In the XOY plane, the two-dimensional distance between each laser point and the midline of the drawn wire is found. If the distance between the two wires is below a certain critical value, it is regarded as a point on this wire. This process continues until there is no trigger. This allows the laser to be collected on each wire.

4) Considering that the power line is a curved surface, the collected laser spot is irregular around the power line, and the block mass center analysis method is used to extract the 3D node of the power line. The extracted wire data is divided into several blocks, and the centroid of each block is obtained (Figure 1 is quoted in Sensors 2019, 19(23), 5059), and the centroid of these blocks is taken as the 3D node of the wire. Finally, the transmission line vector is reconstructed based on the extracted wire space nodes. The surface fitting of any form of transmission line can be realized.

B. Extraction of other ground objects from airborne laser point cloud

In addition to non-ground surfaces such as transmission lines and towers, other ground objects can also be extracted, among which plants and buildings are many. In the preprocessing stage of point cloud, the non-surface objects are divided into spherical surface objects, planar surface objects and bar surface objects according to certain categories. The area growth method is used for the points that are pre-divided into planar objects [8]. The seed points are taken as the seed points, and the points with relatively close distance and height between the points are taken as the growth criteria. After regional growth, the planar objects are obtained. Because the area of the house is fixed, and the distribution of laser spots on the roof of the house is more balanced, the number of laser spots can reflect the size of the roof tiles in a certain sense. An integration-based method is proposed to remove objects with limited coverage, which can be dense tree canopies or other noisy objects. This will give you the target point of the building. On the non-ground surface of the transmission line, the laser spots are mainly plants, with only a few or no building points, and after the construction is removed, the remaining laser spots are basically plants. Because of its own growth characteristics and irregular shape, plants are difficult to obtain and measure, and become the most serious channel characteristics [9]. At present, the research of plant features in aerial LiDAR data has been more in-depth. NDVI based on high-precision remote sensing image inversion can realize the efficient extraction of vegetation [10]. The existing research mainly uses multiple echo information in point cloud to extract vegetation. Although this method can improve the recognition rate of plants, in some cases, it is often unable to obtain multiple echo information. Support vector machines (SVM) have been combined with differential geometric features of roof surfaces for automatic detection of plant bodies in point clouds. However, SVM is a guided class, and its results are often severely restricted by sample quality. Aiming at the shortcomings of the above three algorithms, a fast 3D point cloud acquisition algorithm based on Lidar point cloud is proposed.

In this paper, two characteristics are used to characterize vegetation, namely, vegetation apex and vegetation radius. Firstly, some of the maximum altitude points in the model are taken as its vertices. CHM is a representation of the elevation of surface vegetation objects, which can reflect the spatial distribution of surface vegetation along the elevation and horizontal space [11]. In order to facilitate the analysis and processing of point clouds, the CHM is expressed in grid, and the size of grid elements is determined according to the concentration of point clouds. For different plant nodes, Delauney irregular triangle network is constructed to obtain the neighbor connections between plant nodes, and the points with large height difference between neighboring nodes are taken as plant boundary points. By analyzing the distance between each point in each region, the average distance between each point in each region is obtained, and the average radius is used to represent the diameter of the plant in this region [12]. According to the criterion that the extracted feature must contain a certain number of laser points, the feature containing noise source is removed. This method is used to extract the safe distance in the laser point cloud for the next step. The extraction process of other ground objects in airborne laser point cloud is shown in Figure 2 (see Sensors 2023, 23(21), 8841).

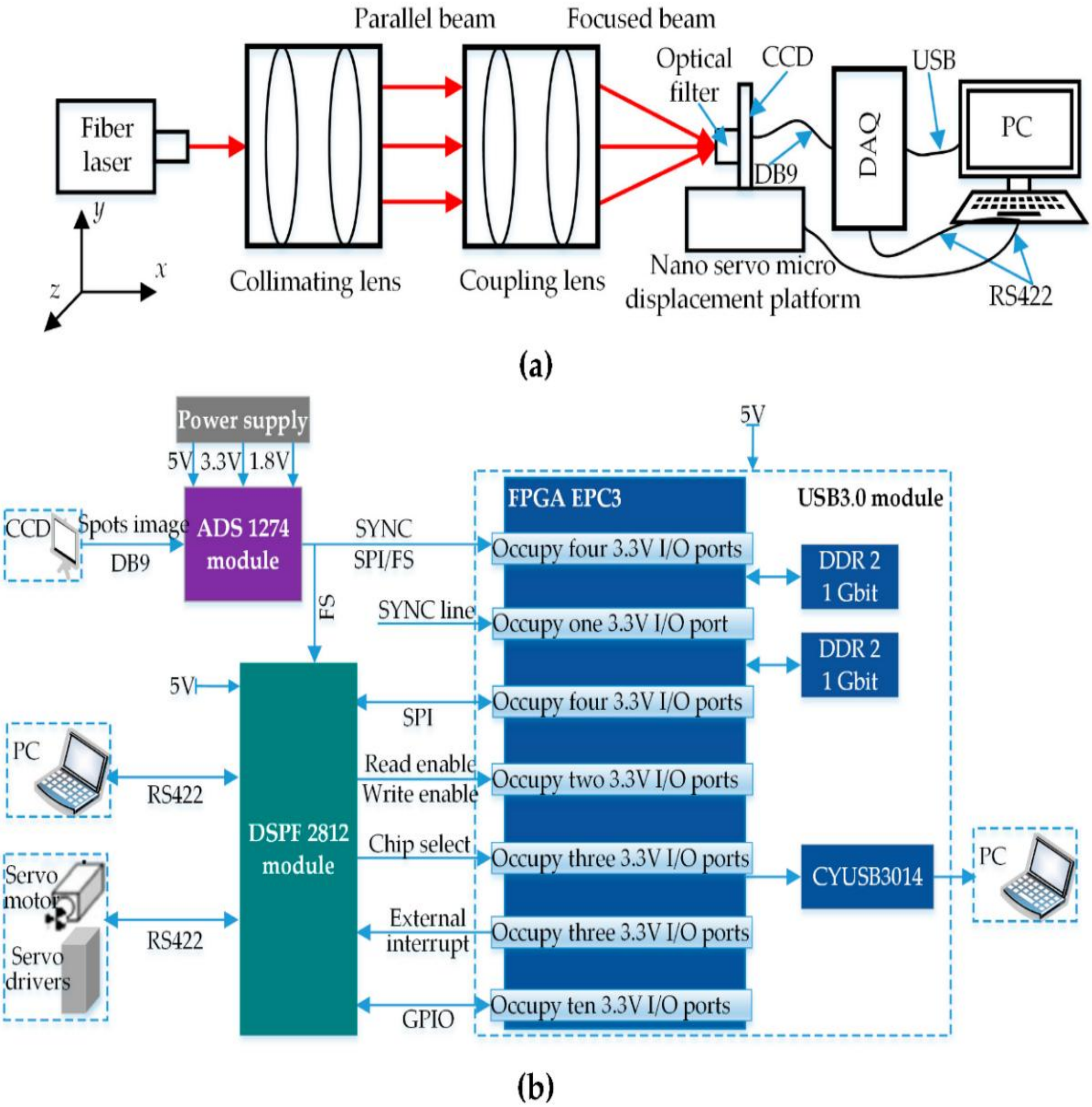


Fig.1 Schematic diagram of region segmentation and centroid extraction

C. Analysis of potential accidents

Through the calculation of the above two steps, the information of ground points, buildings, vegetation, towers and wires in the traverse channel is obtained, and the accurate measurement of the traverse and surrounding objects is realized. The horizontal and vertical distance between ground targets (such as vegetation, buildings, etc.) and power lines. DL/T747-2001 describes in detail the safety spacing of cables of various voltage levels in the "Regulations for the Operation of Overhead Transmission Lines". Most power outages caused by tree flashes are caused by trees outside the cable channel falling into the cable channel [13]. In order to prevent power transmission interruption caused by the collapse of a tree, it is required that the top of the tree must be a certain safe distance from the power line when it falls. Therefore, the safety distance between the poles and towers should also be considered by the parameters such as tree height and width based on measuring the vertical distance between the top of the transmission line and the ground [14]. Using the center and radius of the circle of the plant target obtained, the shortest distance between the target and the wire is determined at the intersection of the target and the surface, so as to measure its safety distance. If this distance exceeds the set safety distance threshold, it is considered to meet the design requirements, otherwise it will be warned. Figure 3 shows the hidden danger analysis process of transmission lines (the picture is quoted in Lightning risk assessment model for transmission lines with lift-based improved analytic hierarchy).

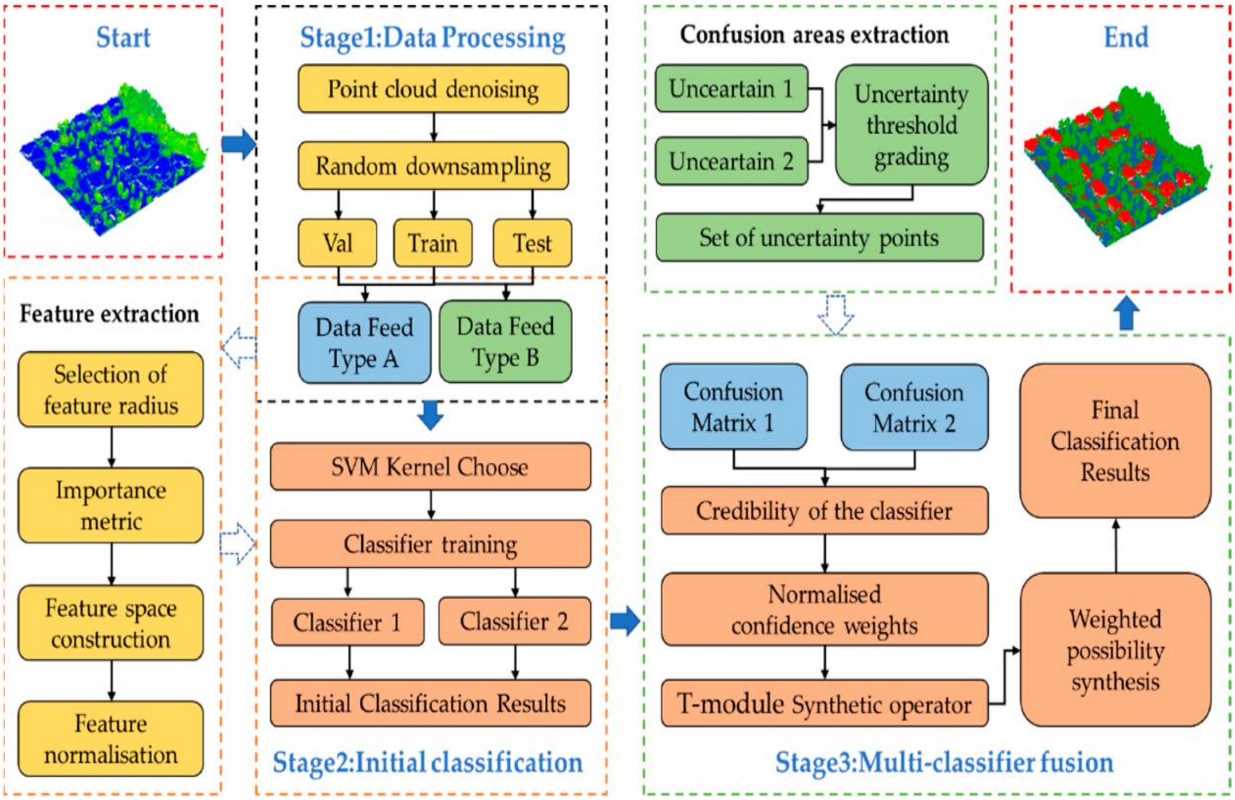


Fig.2 Extraction process of other ground objects in airborne laser point cloud

III. AUTOMATIC ACQUISITION OF POWER LINE POINT CLOUD DATA BASED ON 3D DATA

An automatic power line information extraction algorithm is studied under complex conditions. First, in the case of topographic relief, vegetation interference and other factors, top-down filtering is carried out based on raster data to remove surface object targets and use density descriptors based surface object segmentation [15]. Secondly, the radial optimization method is used to obtain the optimal solution of the transmission line. The experimental results of transmission lines covering multiple regions and tower types show high accuracy in practical application, with the overall accuracy reaching 99.69%.

A. Sorting of wire tower under complex conditions

The transmission channel obtained by aerial LiDAR not only contains power line point clouds, but also contains a large number of ground objects and electronic towers, which need to be pre-processed to obtain power lines. Aiming at the irregularity of complex landform and ground object data, a new idea of segmentation of ground object objects from top to bottom was proposed [16]. By stratifying ground object objects and classifying the density characteristics of ground objects, the problem of high-precision transmission line data extraction under complex conditions was solved. The pre-processing flow is shown in Figure 4 (image cited in 3D laser point cloud clustering method based on image information constraints).

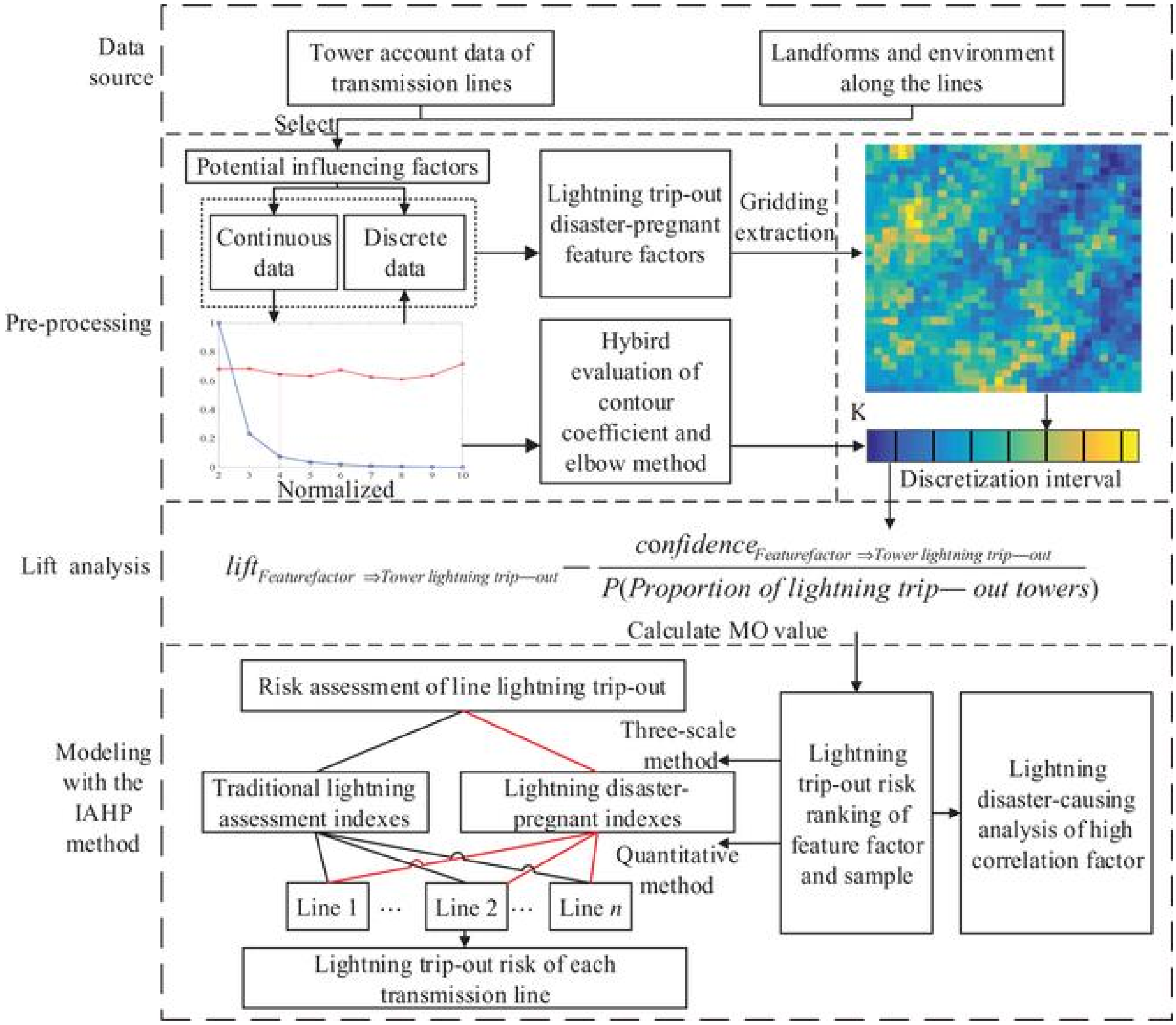


Fig.3 Transmission line hidden danger analysis process

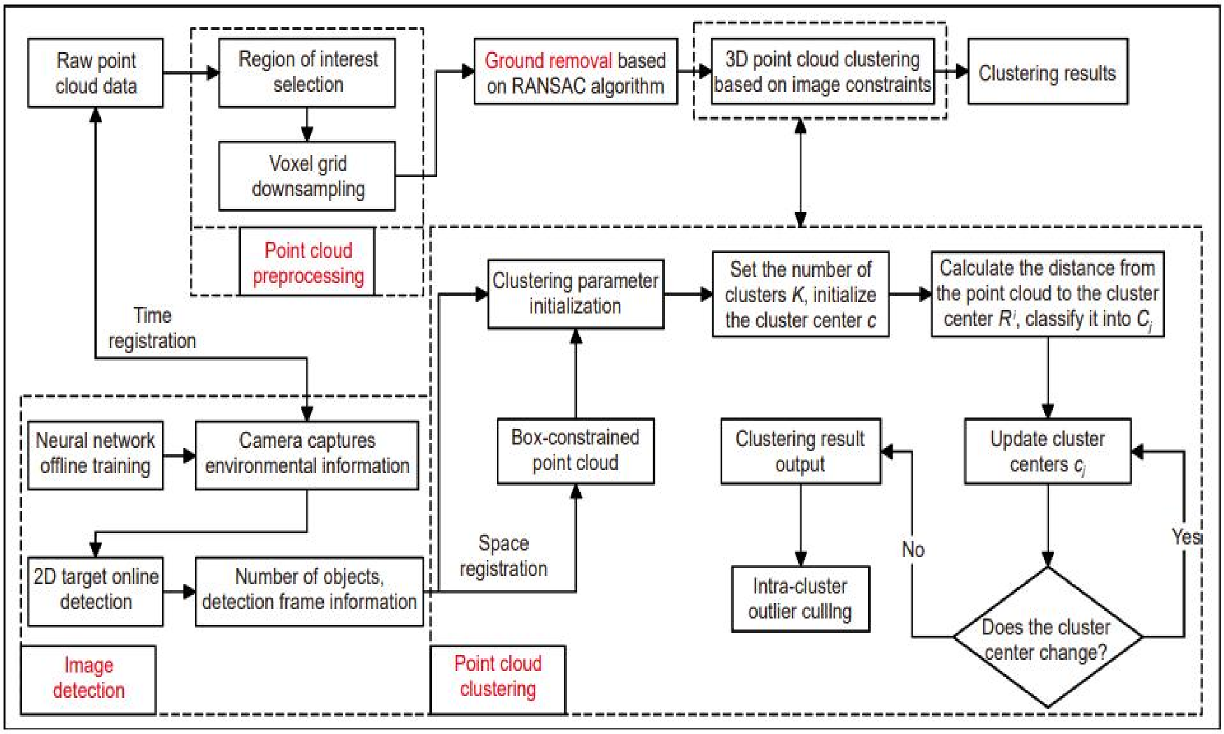


Fig.4 Point cloud data preprocessing process

B. Top-down point cloud segmentation of ground objects based on spatial meshing

The surface features obtained by Lidar scanning mainly include ground features, buildings and vegetation. In the power lines with severe relief, there is often uneven terrain, that is, there is a certain overlap between ground elevation points and ground elevation points [17]. However, if the long-distance spatial units, the distribution of its point clouds on the plane is equivalent to that on the plane, so that the individual units can be processed accordingly, so that the terrain changes can be better overcome. In addition, the distribution of ground target points is chaotic, and the power point cloud obtained in the air is rarely disturbed by ground target points. In this paper, a top-to-bottom spatial grid denoising algorithm is adopted. Its implementation methods are as follows.

(1) The trajectory of the power cables is discerned utilizing the Principal Component Analysis (PCA) approach: a covariance matrix is formed from the point cloud data, with the principal eigenvalue indicating the predominant orientation of the point cloud, which corresponds to the alignment of the power cables and is designated as the horizontal axis..

(2) Spatial grid division: set the partition scale along axis x as h_x, and divide the original point cloud space R_0 into n spatial grids $R_i (i = 1, 2, 3, \cdots, n)$ along axis x, where n and R_i are defined as:

$$n = \lceil [\max_x(R_0) - \min_x(R_0)] / h_x \rceil \tag{1}$$

$$R_i = q \mid q \in R_0 \wedge i = \lceil [q_x - \min_x(R_0)] / h_x \rceil \tag{2}$$

In the formula, $\max_x(R_0)$ and $\min_x(R_0)$ respectively represent the maximum and minimum x coordinate values of the original point cloud space R_0 on the x axis, q_x represents the x axis coordinate values of any point q in R_0, i represents the serial number of the space grid divided along the x axis, and $\lceil \ \rceil$ represents the integer upward.

(3) Cell division: With h_z as the division scale along axis z, the i space grid is divided into $m_i (i = 1, 2, 3, \cdots, n)$ cells along axis z, expressed as $R_{i,j} (i = 1, 2, 3, \cdots, n; j = 1, 2, 3, \cdots, m_i)$:

$$m_i = \lceil [\max_z(R_i) - \min_z(R_i)] / h_z \rceil \tag{3}$$

$$R_{i,j} = q \mid q \in R_0 \wedge j = \lceil [q_z - \min_z(R_i)] / h_z \rceil \tag{4}$$

Where, $\max_z(R_i)$ and $\min_z(R_i)$ represent the maximum and minimum z coordinate values of the i space grid along the z axis, respectively, and j represents the serial number of the subspace divided along the z axis. The original point cloud space grid division process is shown in Figure 5 (the picture is quoted in ISPRS Int.J. Geo-Inf. 2021, 10(7), 482).

(4) Use the top-down search algorithm to eliminate ground object points: each spatial grid $R_i (i = 1, 2, 3, \cdots, n)$ is processed. Since the width of the transmission corridor is similar to the width of the cross arm of the power tower, the initial distance of the transverse power line is set as h, and combined with the characteristics of sudden changes in the width of the plane where the ground object is located, the maximum and minimum y coordinate values on the plane where the ground object is located are determined as the boundary values $y_{\max}$ and $y_{\min}$. A large number of ground object points are eliminated by deleting the point cloud outside the boundary value [18]. Then, combined with the number of power lines n_{line} projected by the point cloud on plane xOz, the processed spatial grid is searched from the top down. When the number of power lines searched is equal to the number of power lines n_{line} entered, the height k corresponding to the completed search is the cutting threshold, and the point cloud below the height k is deleted to achieve the elimination of ground object points under the vertical distance of power lines. Finally, the object points in each spatial grid are eliminated.

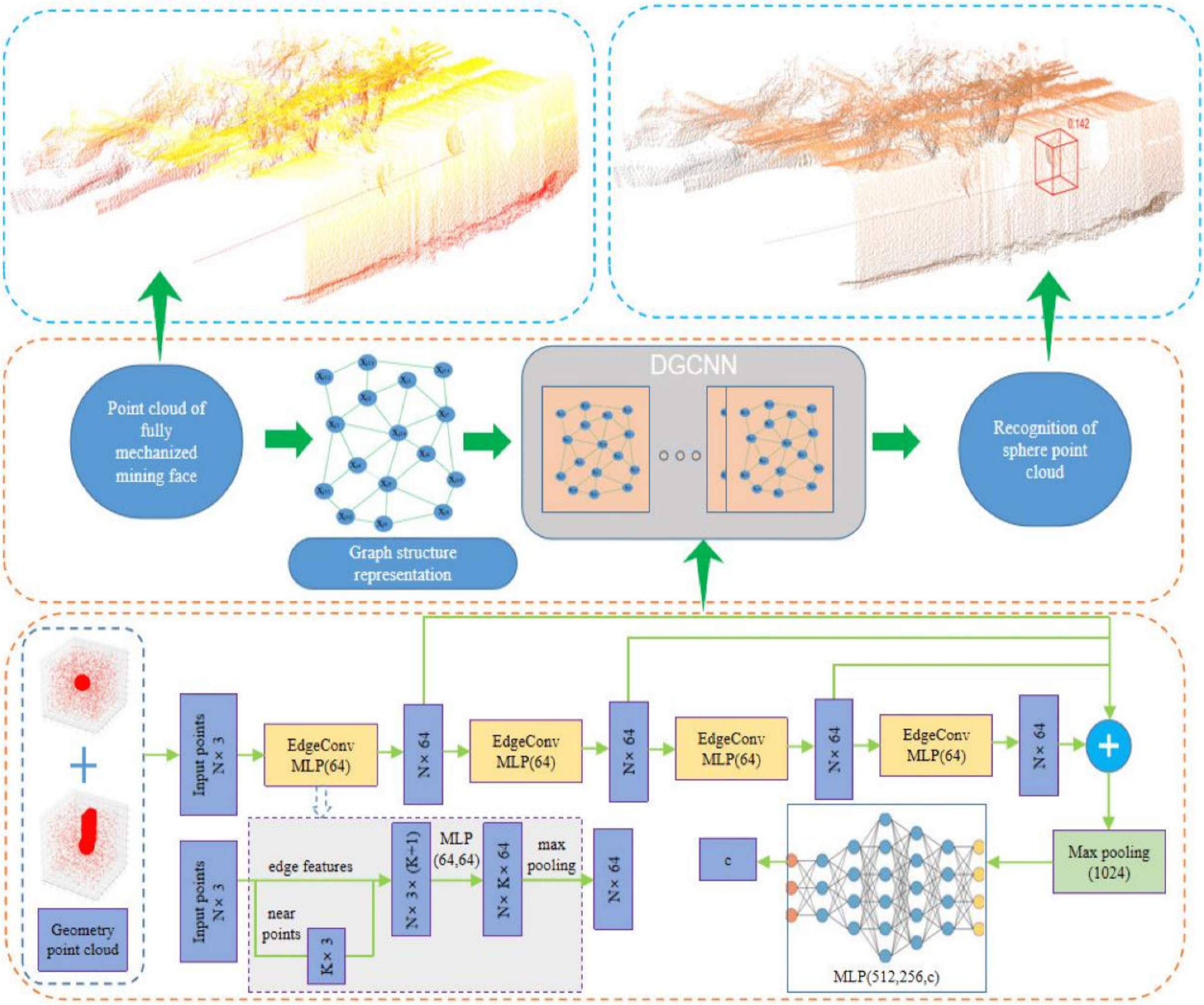


Fig.5 The process of original point cloud spatial meshing

C. Line tower point cloud segmentation based on density descriptors

After the processing of the above method, only the downline tower point cloud and a few high-altitude flying points are left, and these data are often high-altitude areas, and have no impact on the subsequent extraction of the power line. This paper presents an automatic transmission line extraction method based on wavelet transform [19]. This project intends to use the dense observation data based on dense point clouds, combined with the low density of point clouds of neighboring power lines, and adopt the density statistical method based on point clouds to segment the transmission tower. The space grid $R_i^*(i=1,2,3,\cdots,n)$ after removing ground object points is segmented: with h_y as the partition scale along the y axis, the space grid is segmented into m_i cells along the y axis, each cell is represented as $R_{i,j}^*(i=1,2,3,\cdots,n;\ j=1,2,3,\cdots,m_i)$:

$$m_i=\left\lceil[\max_y(R_i^*)-\min_y(R_i^*)]/h_y\right\rceil \tag{5}$$

$$R_{i,j}^*=q\mid q\in R_i^*\wedge j=\left\lceil[q_y-\min_y(R_i^*)]/h_y\right\rceil \tag{6}$$

Where, $\max_y(R_i^*)$ and $\min_y(R_i^*)$ represent the maximum and minimum y coordinate values of the i space grid along the y axis, respectively.

The specific partition process is shown in Figure 6 (the picture is quoted in Mesh Generation). $g_{i,j}$ indicates whether there are some clouds in the j subgrid of the i spatial grid [20]. For the i spatial grid, if there is a cloud in the cell, $g_{i,j}=1$, otherwise $g_{i,j}=0$, then the density descriptor ξ_i is represented by:

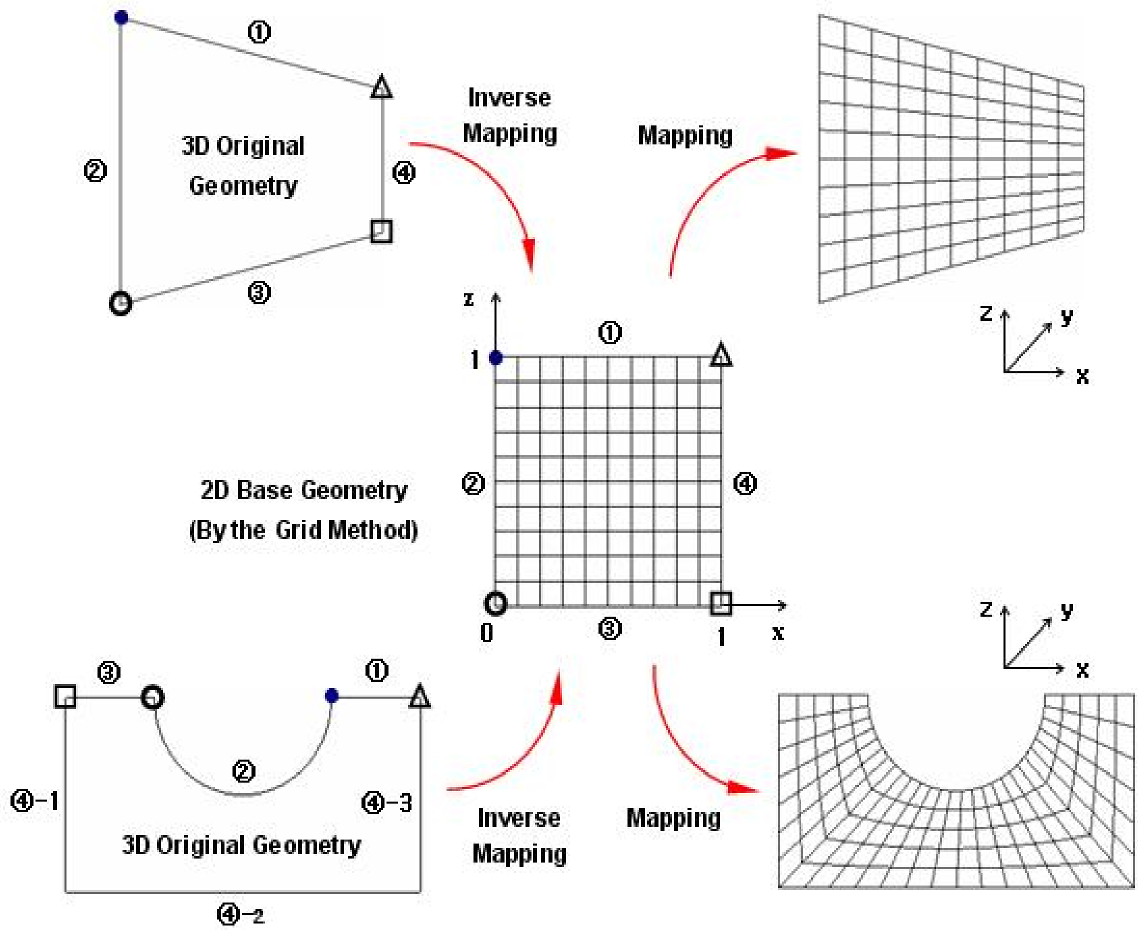


Fig.6 Space grid division process

$$\xi_i = \sum_{j=1}^{m_i} \frac{g_{i,j}}{m_i} \tag{7}$$

By setting appropriate density descriptors, we can realize the whole division of line tower point cloud, the whole division of transmission line point cloud, and the single file partition of transmission line. The experiment shows that this algorithm can remove simply and efficiently.

IV. TEST RESULTS

A fault diagnosis system of safety spacing is developed, and the designed safety spacing is tested based on Microsoft Visual Studio 2012. The corresponding test data are established based on some point cloud data of 220 kV line [21]. Data 1 is obtained based on manned airborne LiDAR (LiDAR), and its point cloud area is 0.6kmx0.3km. The point cloud information obtained when the point cloud is distributed on one tower is shown in Figure 7. This project intends to adopt the point cloud obtained by the Z5 UAV power line inspection platform, including 0.4km * 0.1km, with a point density of 155 points per square meter, covering 3 base stations.

Figure 7 shows an airborne point cloud automatic filtering algorithm that takes into account the surface fluctuation characteristics, which can achieve accurate segmentation of surface and non-surface points [22]. The points and some tower points were completely preserved. This method uses the dimensional characteristics of the image to determine the type of laser spot, leaving only the rod target parallel to the XOY plane. Hough transform can be used to detect a large number of lines. Histogram statistics are adopted to select the direction of the corresponding wave crest as the main direction, and the line represented by the histogram bar with wave crest is taken as the main direction of the power line, so as to achieve the purpose of removing the gross error. 2.5 points to the left of the main direction are identified as the receiving area, which is used to remove incorrectly drawn lines [23]. The midline of the power supply line on the XOY projection plane is obtained by fitting the power supply line with the least square method. After removing the transmission lines and transmission lines, there are vegetation, buildings and other features in the surface point cloud. An algorithm based on area growth is used to segment building units in point cloud. The CHM model was constructed on vegetation points and the point clouds contained in it were extracted from non-feature points (Figure 8 cited in Remote Sens. 2019, 11(22), 2600).

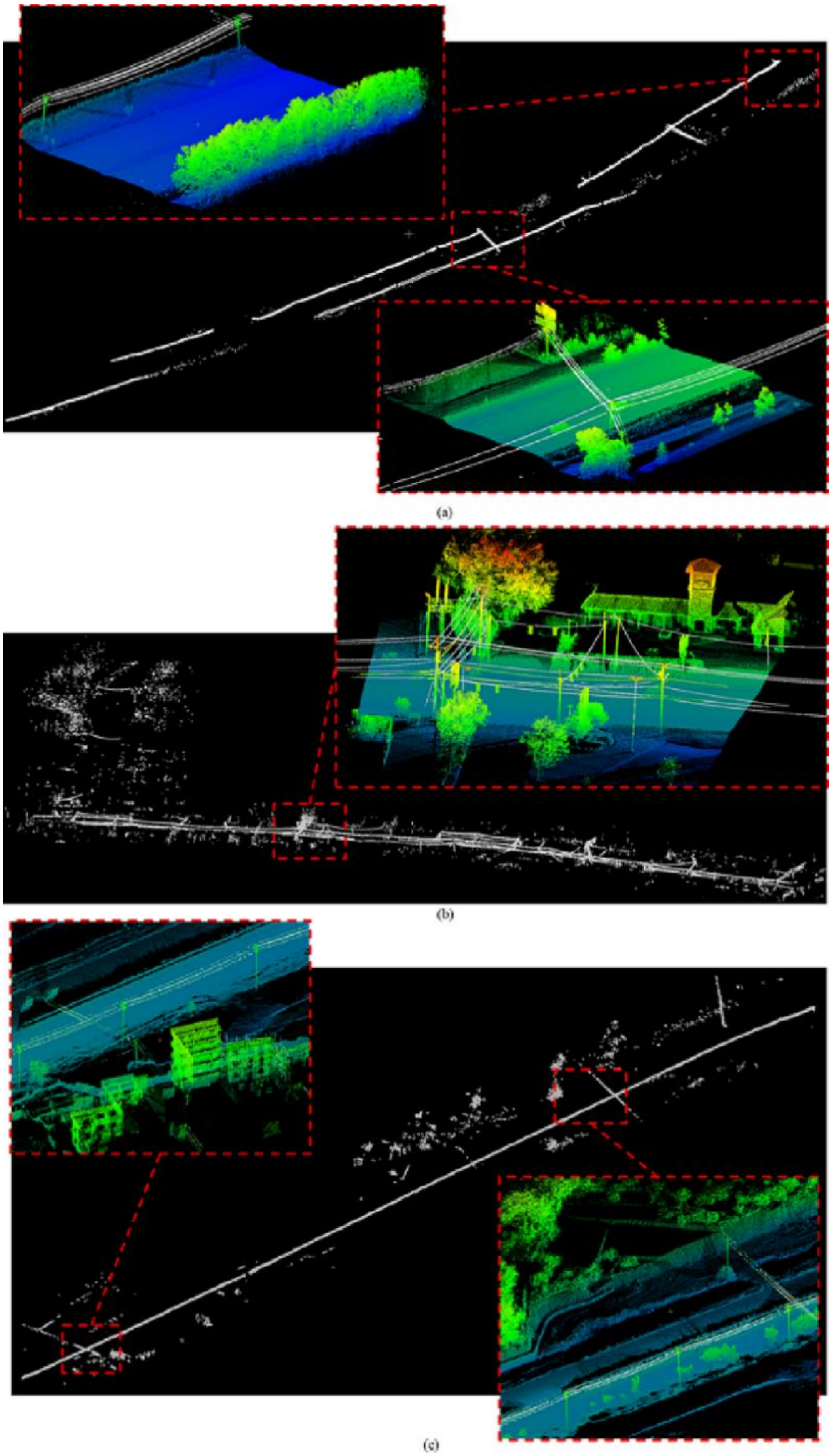


Fig.7 Point cloud data preprocessing

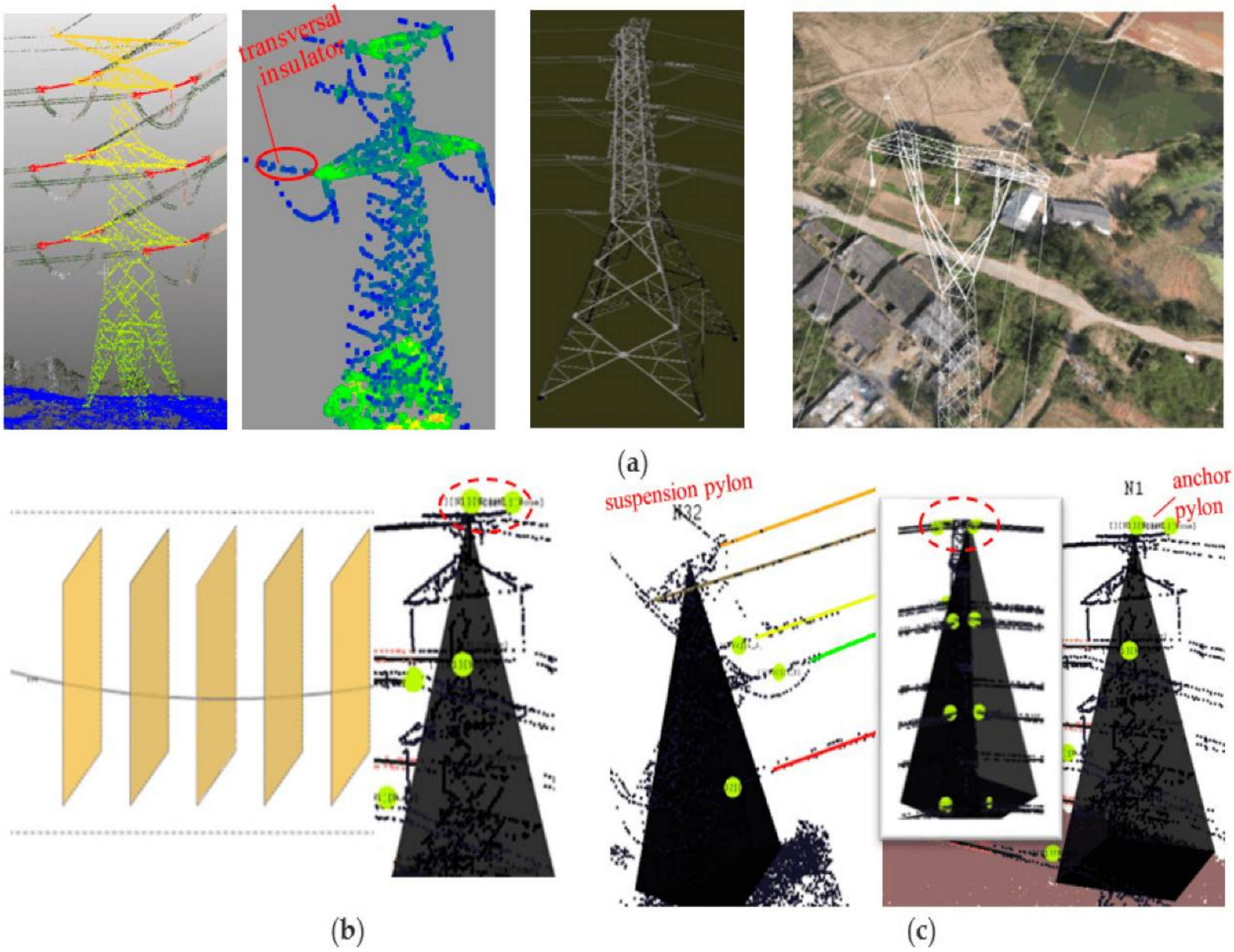


Fig.8 Target recognition in point cloud data

The total station instrument was used to accurately measure discrete observation points of transmission wires and compare the extracted results. The measurement accuracy of transmission wires is shown in Table 1.

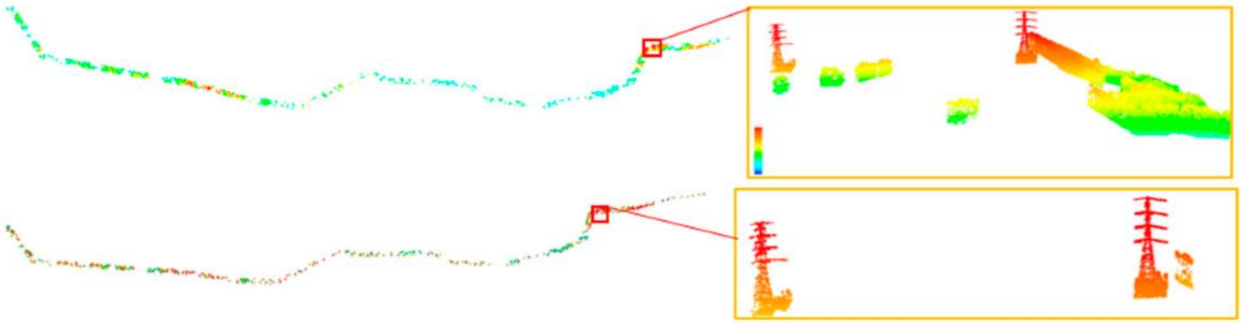
Table 1 Measurement accuracy of power lines

data set	Maximum error	Minimum error	Average error	Mean error
Data 1	0.24	0.06	0.16	0.07
Data 2	0.14	0.03	0.09	0.05

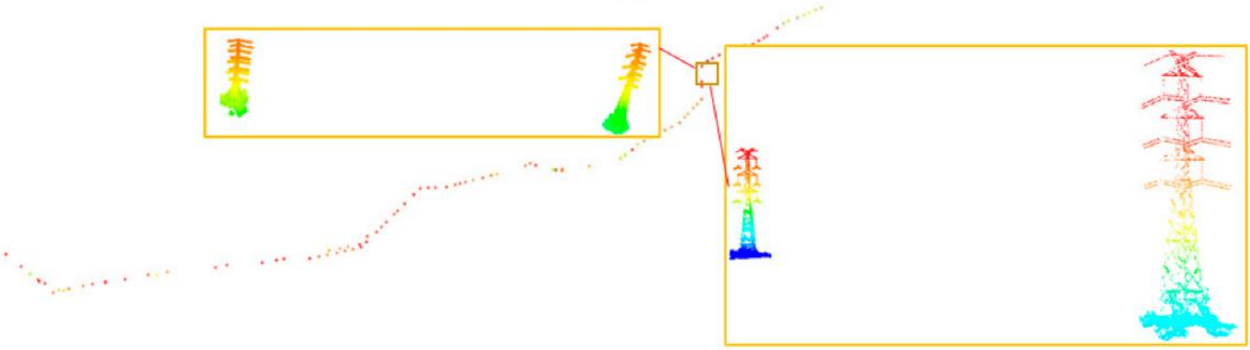
In this paper, a calculation method based on the safety distance between forest and house is proposed, taking the safety distance between forest and house as the calculation limit in the Operation Regulation of Overhead transmission Line. By analyzing the transverse and longitudinal distance between the extracted laser points of buildings and forest land and the fitted grid vector, the alarm beyond the critical value is proposed. Figure 9 is a graph of the safety spacing test results in the laser point cloud data set, while objects beyond the warning range are expressed in prominent colors [24]. Among them, the blue dot cloud is the extraction of pole and tower point clouds, the green dot cloud is the extraction of power line point clouds, and the red is the object beyond the warning range, and the corresponding disaster subsidence. The algorithm can accurately and efficiently detect the overlimit objects in the wire channel, and realize the intelligent diagnosis of the safety spacing of the power grid. The Danradium Line A B detection data set has no features beyond the altitude limit.

V. Conclusion

Aviation Lidar LiDAR can quickly and accurately obtain the electrical equipment . Lidar has been gradually used for transmission line inspection and maintenance. In this paper, a new technology of safety spacing diagnosis for power lines using Lidar point cloud is studied. Objects such as ground, towers, transmission lines, buildings and vegetation are separated, and the distance between power lines and other objects is measured, and the over-limit objects are warned according to the corresponding safety regulations. The method is experimentally studied by using active and unmanned aerial vehicle (UAV) line patrol point cloud to verify the correctness and practicability of the method. The fault diagnosis method proposed in this paper can judge the buildings, plants and other objects around the pipeline, and if they have reached a certain alarm height or orientation, the operation and maintenance personnel can repair or remove them to ensure the safe operation of the pipeline. By modeling the growth of plants and other objects, and predicting their heights, the "safety spacing" detection is transformed from "monitoring" to "early warning", and the flexible regulation of the "pruning" process of plants in the "power grid corridor" is realized to prevent the failure of "paths" such as "tree barriers".



(e)



(f)

Fig.9 Safety distance warning

ACKNOWLEDGEMENTS

Technology project of State Grid Jibei Electric Power Co. LTD. UHV Branch： Research on Real-time Spatial Distance Acquisition Method for Transmission Lines Combining Laser Point Cloud and Image Monitoring (B3018H230008)

REFERENCES

[1] Kyuroson, A., Koval, A., & Nikolakopoulos, G. (2023). Autonomous Point Cloud Segmentation for Power Lines Inspection in Smart Grid. IFAC-PapersOnLine, 56(2), 11754-11761.

[2] Chen, Y., & Ding, X. (2023). A survey of sag monitoring methods for power grid transmission lines. IET Generation, Transmission & Distribution, 17(7), 1419-1441.

[3] Zhou, H., Xu, C., Tang, X., Wang, S., & Zhang, Z. (2022). A review of vision-laser-based civil infrastructure inspection and monitoring. Sensors, 22(15), 5882.

[4] Arikumar, K. S., Deepak Kumar, A., Gadekallu, T. R., Prathiba, S. B., & Tamilarasi, K. (2022). Real-time 3D object detection and classification in autonomous driving environment using 3D LiDAR and camera sensors. Electronics, 11(24), 4203.

[5] Mahin, A. U., Islam, S. N., Ahmed, F., & Hossain, M. F. (2022). Measurement and monitoring of overhead transmission line sag in smart grid: A review. IET Generation, Transmission & Distribution, 16(1), 1-18.

[6] Laninga, J., Nasr Esfahani, A., Ediriweera, G., Jacob, N., & Kordi, B. (2023). Monitoring Technologies for HVDC Transmission Lines. Energies, 16(13), 5085.

[7] Wang, L., Wang, B., Zhang, J., Ma, H., Luo, P., & Yin, T. (2023). An Intelligent Detection Method for Approach Distances of Large Construction Equipment in Substations. Electronics, 12(16), 3510.

[8] Xu, Z., Liang, Y., Lu, H., Kong, W., & Wu, G. (2023). An approach for monitoring prefabricated building construction based on feature extraction and point cloud segmentation. Engineering, Construction and Architectural Management, 30(10), 5302-5332.

[9] Tan, J., Zhao, H., Yang, R., Liu, H., Li, S., & Liu, J. (2021). An entropy-weighting method for efficient power-line feature evaluation and extraction from lidar point clouds. Remote Sensing, 13(17), 3446.

[10] Li, C., Shinkuma, R., Sato, T., & Oki, E. (2021). Real-time data selection and merging for 3d-image sensing network with multiple sensors. IEEE Sensors Journal, 21(19), 22058-22076.

[11] Liu, X., Zheng, W., Mou, Y., Li, Y., & Yin, L. (2021). Microscopic 3D reconstruction based on point cloud data generated using defocused images. Measurement and Control, 54(9-10), 1309-1318.

[12] Lian, X., Liu, X., Ge, L., Hu, H., Du, Z., & Wu, Y. (2021). Time-series unmanned aerial vehicle photogrammetry monitoring method without ground control points to measure mining subsidence. Journal of Applied Remote Sensing, 15(2), 024505-024505.

[13] Luo, Y., Yu, X., Yang, D., & Zhou, B. (2023). A survey of intelligent transmission line inspection based on unmanned aerial vehicle. Artificial Intelligence Review, 56(1), 173-201.

[14] Ren, L., Li, D., Ouyang, Z., & Zhang, Z. (2024). TSE-UNet: Temporal and Spatial Feature-Enhanced Point Cloud Super-Resolution Model for Mechanical LiDAR. Applied Sciences, 14(4), 1510.

[15] Lei, Y., Tian, T., Jiang, B., Qi, F., Jia, F., & Qu, Q. (2023). Research and Application of the Obstacle Avoidance System for High-Speed Railway Tunnel Lining Inspection Train Based on Integrated 3D LiDAR and 2D Camera Machine Vision Technology. Applied Sciences, 13(13), 7689.

[16] Zhou, Y., Xu, C., Dai, Y., Feng, X., Ma, Y., & Li, Q. (2022). Dual-view stereovision-guided automatic inspection system for overhead transmission line corridor. Remote Sensing, 14(16), 4095.

[17] Qi, L., Huang, L., Zhang, Y., Chen, Y., Wang, J., & Zhang, X. (2023). A real-time vessel detection and tracking system based on LiDAR. Sensors, 23(22), 9027.

[18] Ren, Z., & Wang, L. (2022). Accurate real-time localization estimation in underground mine environments based on a distance-weight map (DWM). Sensors, 22(4), 1463.

[19] Aminzadeh, A., Sattarpanah Karganroudi, S., Meiabadi, M. S., Mohan, D. G., & Ba, K. (2022). A survey of process monitoring using computer-aided inspection in laser-welded blanks of light metals based on the digital twins concept. Quantum Beam Science, 6(2), 19.

[20] Chen, Y., Wang, Y., Tang, X., Wu, K., Wu, S., Guo, R., ... & Dong, E. (2023). Intelligent power distribution live-line operation robot systems based on stereo camera. High Voltage, 8(6), 1306-1318.

[21] Zhao, W., Dong, Q., & Zuo, Z. (2023). A point cloud segmentation method for power lines and towers based on a combination of multiscale density features and point-based deep learning. International Journal of Digital Earth, 16(1), 620-644.

[22] Ma, Y., Yu, Z., Zhou, Y., Li, Q., & Wu, Y. (2022). UAV system with trinocular vision for external obstacle detection of transmission lines. Applied Optics, 61(12), 3297-3311.

[23] Khairadeen Ali, A., Lee, O. J., Lee, D., & Park, C. (2021). Remote indoor construction progress monitoring using extended reality. Sustainability, 13(4), 2290.

[24] Lu, Z., Gong, H., Jin, Q., Hu, Q., & Wang, S. (2022). A transmission tower tilt state assessment approach based on dense point cloud from UAV-based LiDAR. Remote Sensing, 14(2), 408.