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EXTRACTION AND MODELING OF INDIVIDUAL SIKANG PINE STEM BASED ON POINT CLOUD DATA

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Forest structure parameters are important parameters in tree volume and biomass estimation. Sikang pine (Pinus densata) is one of the main coniferous species and the pioneering tree species for barren mountain afforestation in western China. Its stem has the characteristics of tall and straight and has important timber value. In order to promote the ecological study of Sikang pine forest, with the point cloud of Sikang pine natural forest obtained by terrestrial laser scanning as the data source, the point cloud clustering algorithm based on Euclidean distance, the comparative shortest-path algorithm and the point cloud cylinder detection and extraction algorithm were used to extract and model of Sikang pine stem. The results show: (1) point cloud data can be used to extract stem from natural forest, and good extraction results can be obtained in natural forest with complex growth environment; (2) the higher extraction accuracy of the lower part of stem can be achieved, and it can be used to build a stem model. Research shows that the stem can be extracted well based on the point cloud data and can be modeled. But due to severe canopy occlusion in the upper stem, the high-precision extraction of upper stem point clouds needs further study.

Key words: *Pinus densata, terrestrial laser scanning, point cloud data, stem extraction, modeling*

Introduction

Sikang pine (*Pinus densata*) is typical for western China. It has the characteristics of high growth, straight stem, and wide use of timber (Lu, Pan, 2008). It is an important tree species for forest greening and afforestation, and has important ecological and economic values. In recent years, many scholars have conducted various research of Sikang pine, including growth environment, forest fire prevention, biomass, forest parameters and carbon storage, etc. (Zhang et al., 2012; Li et al., 2016; Wang et al., 2019; Xiong et al., 2017). The growth morphology of the tree stem is one of important indicators for forest evaluation. Extracting the stem in the natural forest can provide the data basis and reference for research on the utilization and protection of this species.

The traditional forestry stem survey method requires investigators to go deep into the forest area for measurement and statistics. Even though this method can ensure the accuracy of the stem measurement, it is time-consuming, labor-intensive, and inefficient. The emergence and development of Light Detection and Ranging (LiDAR) remote sensing technology provides a new method for forest inventory and research. It can efficiently and accurately produce the three-dimensional spatial structure of the forest-point cloud data, and further explore forest data to make up for the shortcomings of traditional methods. Airborne Laser Scanning (ALS) and Terrestrial Laser Scanning (TLS) are currently the two main platforms for the application of Lidar technology in forests (Zhao et al., 2019). At present, forest ecology studies using ALS technology mostly focus on forest biomass and parameter inversion (Naesset, Gobakken, 2008; Wang et al., 2015; Geng et al., 2015). Due to difficulty of obtaining data about the structure of trees below the forest canopy, such as stems, it is difficult to conduct research on the extraction and modeling of stems using ALS technology. TLS point cloud data can clearly and accurately characterize the three-dimensional spatial structure information below the forest canopy, and has great potential for extracting information such as tree stems. At present, most researchers are keen on the extraction of parameters such as tree height and diameter at breast height (Beland et al., 2011; Li et al., 2012; Liu et al., 2014; Liu et al., 2018). And there are few studies on extraction and modeling of individual tree stem in natural forests (Liang et al., 2013; Xia et al., 2015).

Our research aims to extract stem and model the Sikang pine by using point cloud data to provide reference for research on this or other tree species.

Materials and Methods

Data acquisition and preprocessing

Shangri-La City is located in the northwestern part of Yunnan Province (99°33′E – 100°58′E, 27°20′N – 28°09′N), with abundant forest resources and high vegetation coverage. In the study, Leica P40 3D laser scanner was used as the data acquisition equipment, and a natural Sikang pine forest sample plot was selected as the experimental object in Xiaozhongdian County, Shangri-La City, Yunnan Province of China to acquire point cloud data. In order to obtain the complete point cloud data from the research sample plot, 5 sites (1 in the center and 4 nearby) were selected in the sample plot for scanning, as shown in figure 1. After obtaining the cloud data of each site in the sample plot, stitch them to obtain the original point cloud data. Then, the four steps of thinning, denoising, filtering and normalization were preprocessed. Finally, we obtained the complete point cloud experimental data of the Sikang pine by cutting in a circle with a radius of 15 meters, as shown in figure 2.

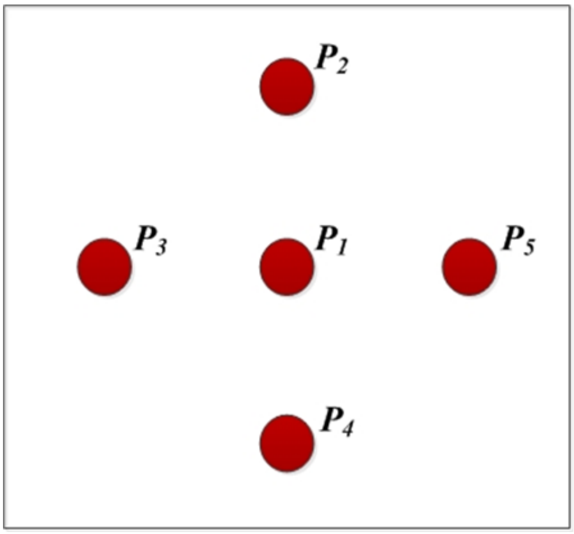

Fig. 1. Scanning station diagram

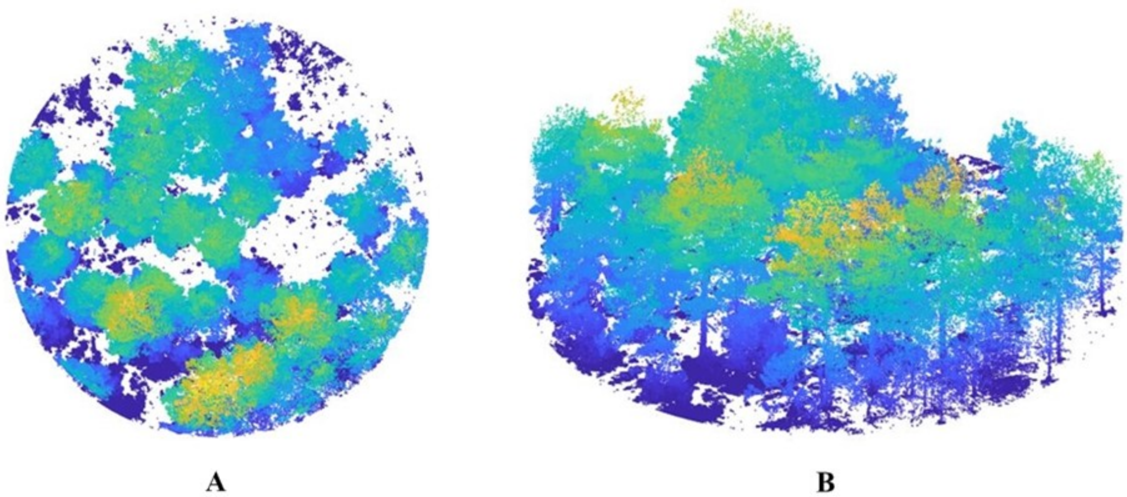

Fig. 2. Experimental data of the Sikang pine A) Top view; B) Front view

Research process

After preprocessing the data, the research firstly clustered the experimental data based on the point cloud clustering algorithm of Euclidean distance in order to filter and remove the point cloud of shrub and grass, and extract the Sikang pine. Secondly, the comparative shortest-path algorithm (CSP) was used to segment the point cloud and extract individual trees. Finally, cylinder recognition was performed on the point cloud of an individual tree, the stem point cloud is extracted, and the cylinder is fitted to obtain the stem model. The research technical route is shown in figure 3.

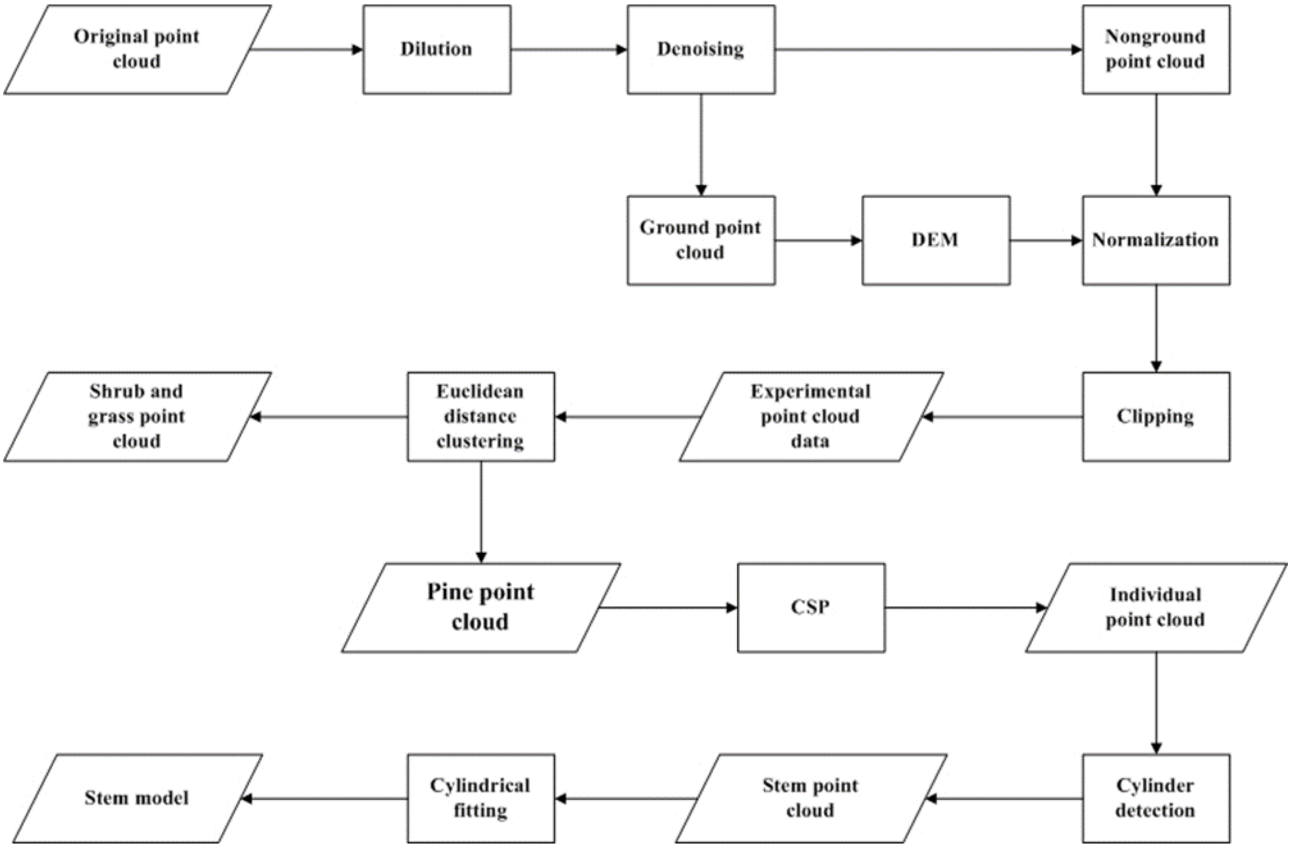

Fig. 3. Technology Roadmap

Euclidean distance clustering

The research uses the point cloud clustering algorithm of Euclidean distance to cluster the Sikang pine point cloud. The Euclidean distance between two points in three-dimensional space refers to the straight-line distance between the two points. The Euclidean distance *d* of two points in three-dimensional space *a* (x1, y1, z1), *b* (x2, y2, z2) is calculated by the formula (1).

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \ . \quad (1)$$

The point cloud is clustered through a given initial distance threshold. If the distance between the two points is less than the given threshold, the two points belong to the same category. According to this principle, the Sikang pine point cloud is extracted. The steps of the algorithm are as follows: (1) load point cloud data and find the ground plane to store it; (2) specify the minimum distance between two different types of clusters, cluster the point clouds that do not include the ground plane, and then assign the same label to the points belonging to the same cluster; (3) give an additional label to the ground plane point cloud; (4) extract point clouds of different categories based on labels. The research explored the minimum distance between two different types of clusters and revealed that when the minimum distance is 0.5m, the Sikang pine clustering result is the best, as shown in figure 4.

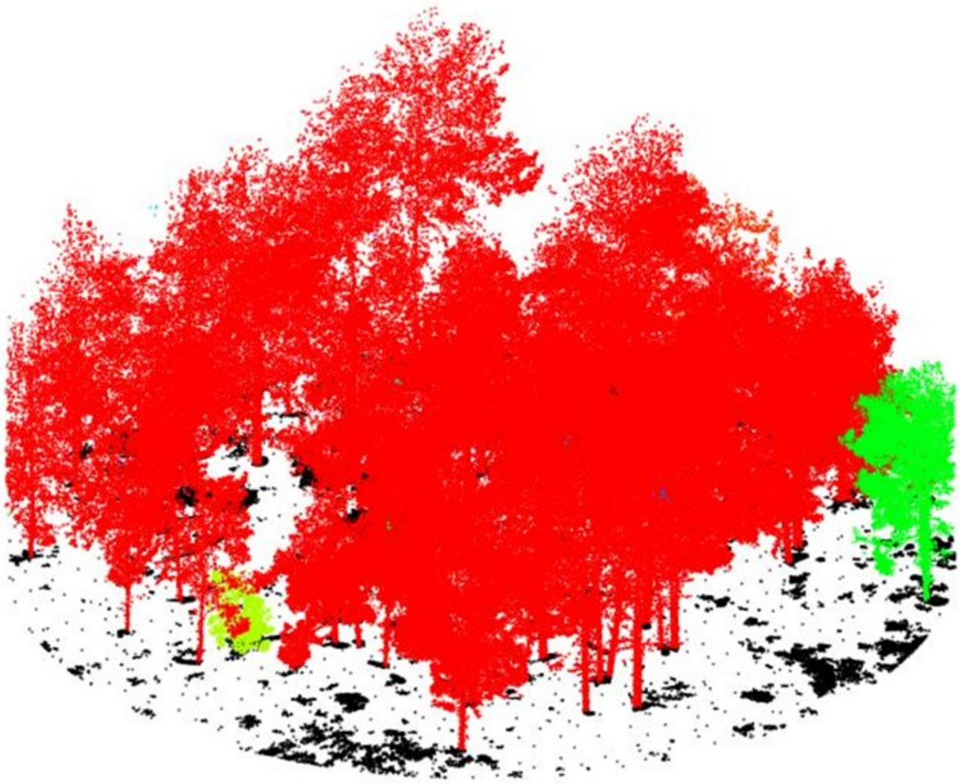

Fig. 4. Clustering results

It can be seen from figure 4 that the Sikang pine is basically clustered, but there are also some independent pines that are divided into different categories (green point cloud). Then we used filter and removed the shrub and grass point clouds in order to extract the Sikang pine, and perform the Sikang pine point cloud fusion using the CloudCompare point cloud processing software to obtain a complete point cloud in the experimental sample plot, as shown in figure 5.

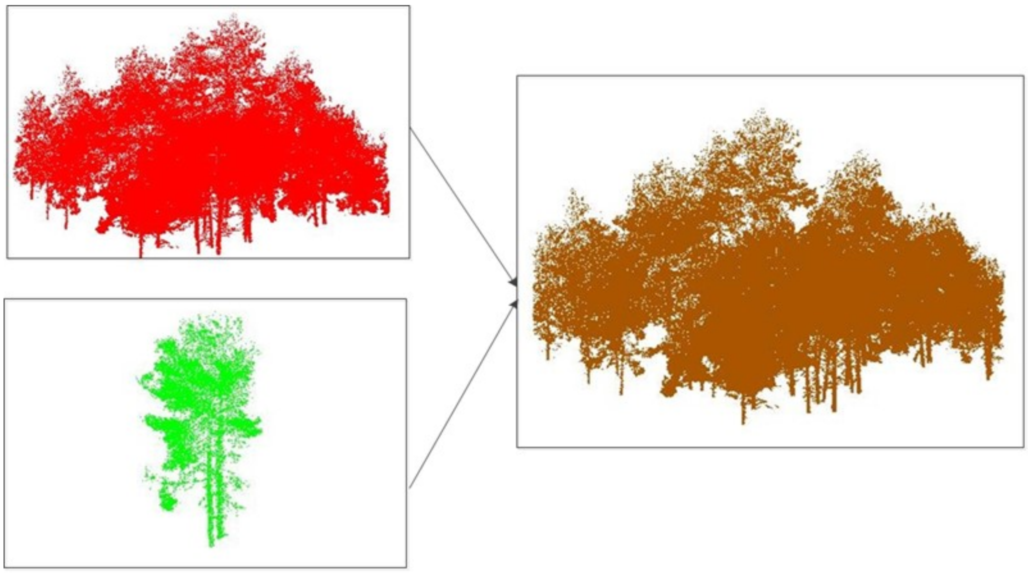

Fig. 5. The merger results of Sikang pine

CSP point cloud segmentation

CSP is a point cloud segmentation algorithm based on ecological theory proposed by Tao et al. (2015). The principle of the algorithm is as follows: according to the ecological theory "there are many conduits for nutrient transport in a tree". Let us assume the conduit from the leaves to the roots of the tree to be the path, and the metabolic distance to be calculated based on the path distance from a leaf to the root, by comparing this metabolic distance. By applying the point cloud individual tree segmentation, we will get that the metabolic distance from a certain point to the root of the A tree is shorter than the metabolic distance to the root of the B tree, then the point belongs to the A tree. The metabolic distance of this path is calculated according to the formula (2):

$$D^{N}_{v \to Trunk} = D_{v \to Trunk} / DBH^{2/3} \ , \tag{2}$$

where, $D^{N}_{v \to Trunk}$ represents the metabolic distance from point v to the stem of the tree, $D_{v \to Trunk}$ represents the actual distance from point v to the stem of the tree, and DBH represents the diameter at breast height of the tree. The result of individual tree segmentation of Sikang pine point cloud by CSP algorithm is shown in figure 6.

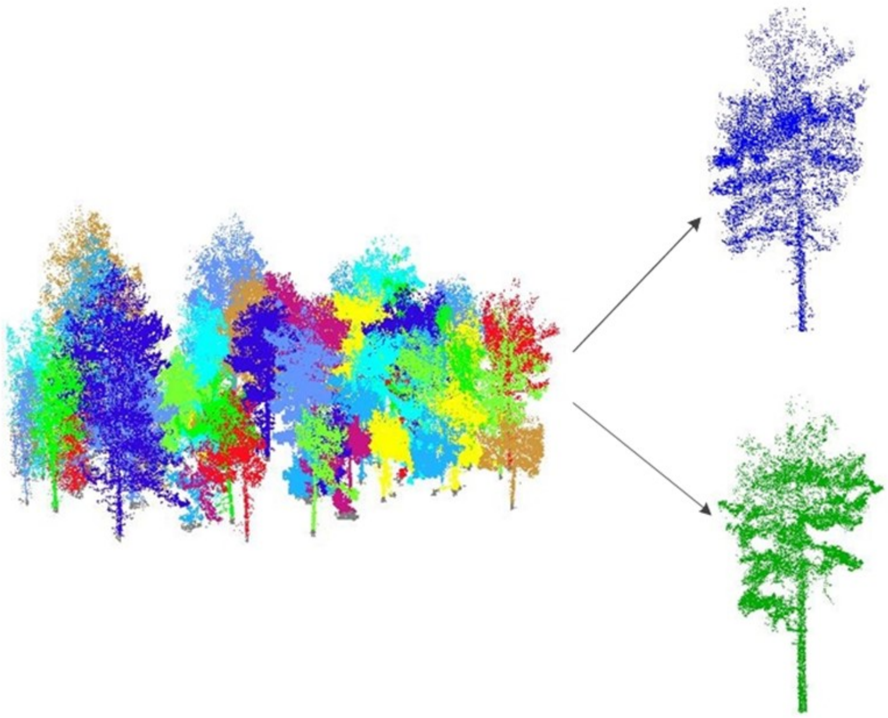

Fig. 6. The individual tree segmentation result of Sikang pine

Point cloud cylinder detection and recognition

The growth morphology of the Sikang pine stem is mainly cylindrical. According to this feature, the point cloud can be identified and extracted, and then the stem cylindrical model can be established. The research uses point cloud cylinder extraction and detection to extract Sikang pine stems. The principle is as follows: given the maximum distance from point to the cylindrical surface, if the shortest distance from point p to the cylindrical surface is less than the given distance, then point p belongs to the point on the tree stem. The steps of the algorithm are as follows: (1) load the point cloud data; (2) set the maximum distance from point to the cylindrical surface; (3) set a coordinate area for cylinder identification; (4) set a normal vector; (5) perform point cloud cylindrical detection and extraction.

Results and discussion

The research combines the point cloud clustering algorithm based on the Euclidean distance and the CSP point cloud segmentation algorithm to extract the individual Sikang pine, then recognizes and detects the cylinder to extract the Sikang pine stem. Sikang pine stem extraction and its stem model results are shown in the figure 7.

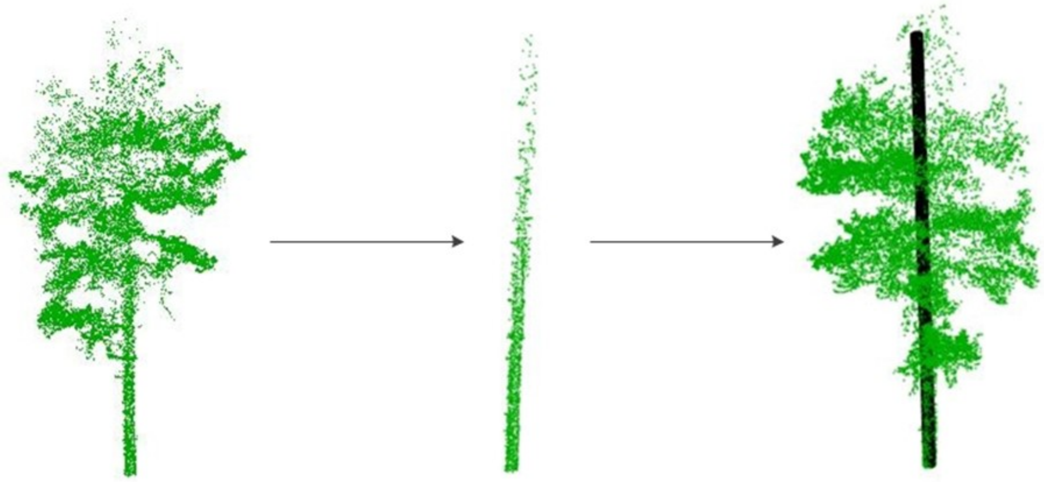

Fig. 7. Stem extraction and modeling results

It can be seen from figure 7 that the results of the stem extraction of Sikang pine are generally good, which was the purpose of the research. However, because the upper stem of the Sikang pine canopy is severely occluded, it is difficult to obtain a complete extraction of the stem point cloud, especially in the upper part of the stem, thus the accuracy of the extraction results is relatively low. The lower part of the stem is not obstructed, and the extraction results are better. This fits the growth results of the stem model and can basically reflect the growth of the stem. However, from the results of the model established by the stem, the thickness of the upper part of the stem model is the same as that of the lower part, which does not meet the actual growth of the stem. Through research and analysis, the upper canopy occlusion is still the main cause of this problem. The experiment was carried out on another Sikang pine natural forest sample plot with a more complicated growth environment. This sample plot contains other tree species and the growth density is also high. In order to improve the accurate identification and extraction of Sikang pine, when collecting point cloud data in this sample plot, the Sikang pine was numbered, and finally the Sikang pine was identified and stem extracted according to this number, in order to eliminate the interference of other tree species in the study. The stem extraction and model results of the Sikang pine in this sample plot are shown in figure 8.

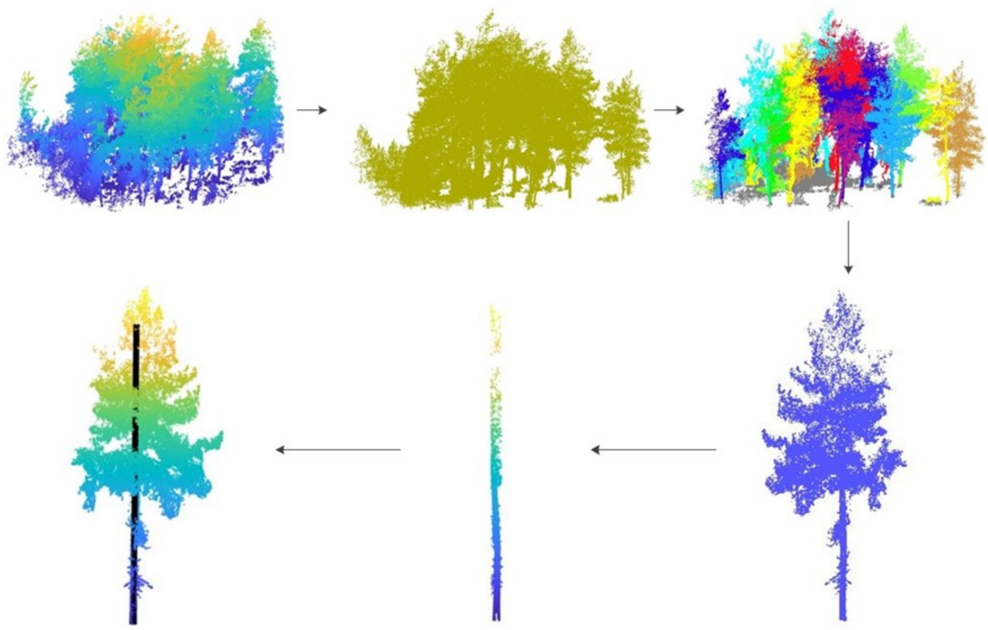

Fig. 8. Extraction and modeling results of Sikang pine stem in complex plots

It can be seen from figure 8 that for the research sample plot with complex growth environment, the stem extraction of Sikang pine based on TLS point cloud data can still be achieved. In particular, the accuracy of the extraction results from the lower part of the stem is good, and can serve as the basis for stem growth model development. However, there are also problems caused by canopy occlusion, and the extraction results of the upper part of the stem are relatively poor. We found there are two main aspects that affect the accuracy of the results, which are point cloud density and canopy occlusion. The influence of point cloud density and canopy occlusion on stem extraction and modeling is discussed below.

1) The effect of point cloud density on stem extraction and modeling.

The point cloud density is usually characterized by the distance between the two points of the point cloud. The smaller the distance between the two points, the greater the number of point clouds and the greater the point cloud density. Through research, the point cloud density has a certain influence on the main extraction and modeling of the Sikang pine. The greater the density of the point cloud, the greater the number of point clouds that make up the stem, and the extracted stem can more accurately reflect the growth of the stem, so that the stem can be modeled more accurately, but calculations increase with the increase of the point cloud density.

2) The influence of canopy occlusion on stem extraction and modeling.

The canopy around the upper part of the stem grows densely, which has an impact on the point cloud acquisition in the upper part of the stem, and it is difficult to obtain a complete point cloud compared to the lower part of the stem. For Sikang pine that the upper canopy of the stem grows sparsely and does not cover severely, the stem extraction results are more accurate and the model is more accurate. For Sikang pine with dense canopy growth, minimizing its influence on stem extraction and modeling will be the next focus of our research.

Conclusion

The research involved stem extraction and modeling of the individual Sikang pine in the natural forest based on TLS point cloud data. The results revealed that: (1) the stem of Sikang pine in natural forests can be extracted well, and good extraction results can still be obtained in natural forests with complex growth environments based on point cloud data. (2) the extraction results of the lower part of the Sikang pine stem are more accurate, and the stem model can be established, which can provide a reference for the forest ecology research of Sikang pine or other tree species. However, due to the complexity of the point cloud data and the occlusion of the upper part of the stem by the canopy, it is difficult to obtain a complete point cloud of the upper part of the stem. Therefore, in future research, it is still necessary to improve the accuracy of point cloud extraction on the upper part of the stem, in order to develop a more accurate model of stem.

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