Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 11, No. 1, 2024

Dynamic Analysis of Street Trees in Vehicle-mounted LiDAR Point Clouds

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Abstract: Street trees, as key elements of urban road scenes, play a significant role in the overall ecological environment and aesthetics of city roads through their dynamic growth and changes. With the continuous development of urban roads, the growth conditions of street trees are also constantly changing. Therefore, studying how to infer the dynamic changes of roads through the variations in street trees is a highly valuable technical issue. This paper delves into several critical parameters of street trees, including diameter at breast height (DBH), tree height, trunk height, crown volume, and crown spread. By updating these parameters, determining transplantation and replanting decisions, and analyzing growth states, we comprehensively analyze the dynamic changes of street trees. To achieve this goal, we integrated multiple parameters into the analysis process of street trees and established a comprehensive analysis system centered on the DBH parameter. Combining this with data visualization technology, we provide an intuitive dynamic analysis method. Experimental results indicate that, compared to single-parameter analysis methods, the multi-parameter comprehensive analysis method demonstrates higher accuracy and stronger persuasive power in the study of dynamic changes in street trees, thereby validating the superiority and practicality of the proposed research algorithm. This research can provide more scientific and reliable references for urban road planning and management.

Keywords: Vehicle-mounted LiDAR, RANSAC, voxel accumulation, multi-parameter, dynamic analysis.

1. Introduction

According to data released by the government website, by the end of 2022, the total area of urban roads nationwide reached 10.893 billion square meters, a year-on-year increase of 3.39%; the length of urban roads was 552,200 kilometers, a year-on-year increase of 3.70%[1]. The 2024 Government Work Report proposed the development of livable, resilient, and smart cities[2]. It is evident that road construction will be a key part of the future development of smart cities. As the most critical and widely distributed feature in road scenes, analyzing the changes in street trees is helpful in studying the characteristics of road changes.

Three-dimensional laser technology[3] has now become an essential method for rapidly acquiring detailed three-dimensional information of surface features with high spatiotemporal resolution. It is widely used in marine, terrestrial, and aviation fields. This technology is characterized by its simplicity, high efficiency, low cost, and high accuracy and resolution, making it adaptable to various complex environments. Currently, significant progress has been made in the analysis and research of street trees.

(1)Street Tree Extraction. In 2012, Monnier[4] achieved the basic segmentation of connected street tree point clouds by projecting point clouds and using the nearest neighbor principle based on the crown center point. In 2013, Zhong Ruofei[5] et al. utilized RGB information from high-resolution panoramic images to segment tree information from non-ground point cloud data and extract attribute information of individual trees. However, this method is limited by image resolution and has poor general applicability, making it unsuitable for widespread application. In 2014, Yang Shasha[6] analyzed different features of various objects and performed feature segmentation based on vehicle-mounted LiDAR data. By projecting 3D graphics onto a 2D plane for processing and using Matable programming, tree information was extracted. Combined with data layering and clustering algorithms, this method achieved the extraction of individual tree information from non-connected trees. In 2016, Zhang Xitong[7] proposed a distance-weighted segmentation method based on a tree growth model, achieving precise segmentation of point clouds of multiple connected trees.

(2)Diameter at Breast Height (DBH) Fitting: Current research primarily fits the DBH as an ellipse or a circle. Ellipse fitting methods include adaptive ellipse fitting[8] and robust least squares fitting[9]. Circle fitting methods encompass image detection-based methods[10-13] (such as Hough transform, camera point clouds, wireframe models, and region segmentation), as well as algebraic and geometric methods[14-22](such as the least squares quadratic screening method, minimum variance iterative algorithm, and ring-neighbor point method). Additionally, model-based methods include the tree height-DBH model and conical geometric model[23-25]. These methods in DBH fitting are affected by image distortion and noise, with the congruence of results to actual features needing verification. The iterative counts are difficult to precisely control due to the influence of tree position and slice thickness, and are susceptible to the quality of original data, resulting in poor robustness. Some models are only suitable for specific types of trees and are difficult to generalize to other species.

(3)Dynamic Analysis of Street Trees: In 2019, Dong Yahan[26] performed a brief classification and dynamic analysis of typical pole-like objects. In 2020, Wang Peng[27] proposed an automatic extraction method for pole targets in vehicle-mounted point clouds based on pole arc features, using a constrained Random Sample Consensus (RANSAC) validation operator to search for arc-shaped point sets, accurately identifying the pole-like parts of pole objects. Li Pengpeng[28] constructed a feature matrix based on point cloud features of pole-like objects and used a sample set to train a BP neural network model to classify pole-like objects in the test area, providing a brief analysis of the dynamic changes of street trees. Current dynamic analysis algorithms are complex, limited in variety, and have poor detection and analysis performance on the original point cloud in dynamic fitting. Some algorithms consider only a single aspect without conducting a comprehensive global analysis, lacking a thorough consideration of the relationships and weights among parameters.

Based on this, this paper uses vehicle-mounted LiDAR point cloud data to obtain high-quality point cloud data of street trees, performing comprehensive parameter extraction and analysis of street trees. By analyzing from the perspective of global feature parameter changes and utilizing multi-period point cloud data of street trees, this study aims to achieve dynamic fitting of street trees to meet predetermined accuracy and requirements.

2. Street Tree Parameter Fitting

The characteristics of street trees can be described through various parameters such as diameter at breast height (DBH), crown volume, bottom center coordinates of the tree, and tree height. Analyzing and fitting these features provides a solid basis for subsequent dynamic analysis. This paper uses data preprocessing techniques (e.g., clipping, segmentation, denoising, etc.) to obtain complete point cloud data of street trees.

2.1. DBH Fitting

This paper proposes a comprehensive DBH fitting algorithm that combines the RANSAC algorithm with the least squares method, incorporating preconditions for posture determination to enhance the accuracy of DBH fitting for street trees.

2.1.1. Posture Line Fitting

The growth posture of street trees is influenced by natural factors (such as sunlight, temperature, etc.) and usually exhibits two postures: vertical and inclined.

Vertical Posture: In this posture, the direction vector of the tree trunk is perpendicular to the geoid level, appearing as perpendicular to the XOY horizontal plane. In this case, the point cloud at the DBH position is projected horizontally onto the XOY plane for DBH fitting.

Inclined Posture: In this posture, the direction vector of the tree trunk forms a certain angle with the normal vector of the geoid level, ranging from 0 to 90 degrees. Since horizontal projection is unsuitable for extracting the DBH of inclined trunks, it is necessary to determine the posture line of the trunk's inclination direction. A plane perpendicular to this posture line is then determined as the projection plane for the DBH, which is then transformed to the XOY plane for DBH fitting. This plane is perpendicular to the posture line, so the posture line must first be fitted.

There are two methods for fitting the trunk posture:

(1) Smooth Curve Fitting Method: This method connects the center coordinate points of all fitted circles of the trunk sections, forming a smooth curve, which is the posture line of the trunk. The purpose of this method is to obtain a smooth curve as the posture line of the trunk, as shown in Figure 1, to complete the trunk posture fitting.

(2) Spatial Line Fitting Method: This method fits the center coordinates of the sectional point clouds in three dimensions, using the least squares method to perform spatial line fitting, thereby obtaining a spatial line that represents the growth direction of the trunk. The aim of this method is to provide a brief representation of the trunk's growth direction.

This paper adopts the second method.

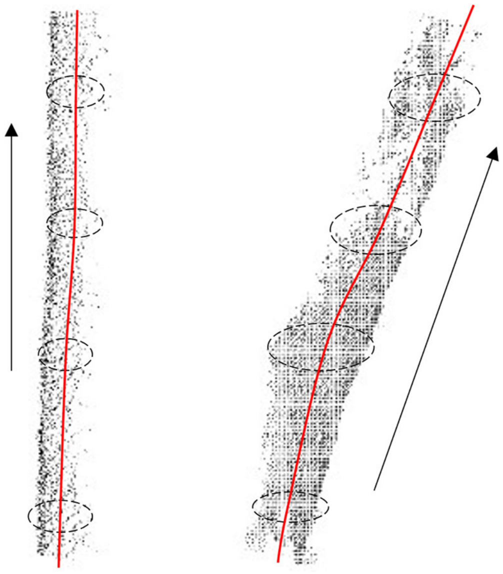

Figure 1. Trunk Posture Line Fitting

2.1.2. Combination of RANSAC and Least Squares

The denoised trunk point cloud is segmented along the plane perpendicular to the posture line to obtain the DBH point cloud, which is then projected onto this plane to generate a 3D projection point cloud. The projection point cloud undergoes coordinate transformation to the XOY plane, resulting in a 2D planar point cloud. The RANSAC algorithm is used to fit the DBH point cloud by randomly selecting three sample point clouds and iterating multiple times to obtain preliminary DBH parameters. Subsequently, the least squares method analyzes the distance from each point in the 2D plane to the circle center, calculating the sum of the orthogonal distances of all points to the circle (i.e., the total error). The DBH parameters with the minimum total error are selected as the final fitting result.

2.2. Trunk Fitting

The trunk is the main structure of a tree, extending from the roots to the starting point of branches. It plays a critical role in supporting the crown and promoting the upward growth of the tree, making it significant in urban greening, urban planning, and urban ecology research. Trunk parameters include trunk height, bottom center coordinates, DBH, and trunk growth posture.

2.2.1. Tree Height Fitting

Tree height fitting involves analyzing the height data of street trees. After obtaining the street tree point cloud, the maximum and minimum values in the elevation (Z-axis direction) are calculated, and their difference is taken as the tree height.

2.2.2. Trunk Height Fitting

Trunk height fitting differs from tree height fitting and requires separating the trunk and the crown. Trunk height is defined as the distance from the lowest point of the trunk base at the ground to the first branch separation point.

(1)Crown and Trunk Separation: A bottom-up grid division method is employed, as shown in Figure 3-13. A 3D grid is established, expanding upwards from the grid containing the point cloud at the bottom. During the calculation, the change in the number of point clouds in adjacent grids is monitored. A significant increase in the number of grids during upward expansion is identified as the boundary point between the crown and the trunk, and separation is performed accordingly.

(2)Trunk Height Calculation: After separating the trunk, the maximum and minimum values of the trunk point cloud in elevation (Z-axis direction) are calculated, and their difference is taken as the trunk height.

2.2.3. Bottom Center and Cross-Section Fitting

The bottom center coordinates and cross-sectional parameters are important indicators of trunk growth, significant for analyzing the spatial distribution characteristics, trunk thickness, and growth straightness of street trees.

(1)Bottom Center Fitting: Bottom center fitting is determined by circle fitting the bottom point cloud of the trunk, rather than simply using the lowest coordinates of the trunk point cloud. This study employs circle fitting on the semicircular feature point cloud generated by 3D laser scanning of the ground corresponding to the trunk bottom, as shown in Figure 2. The 3D coordinates of the fitted circle center are taken as the bottom center coordinates.

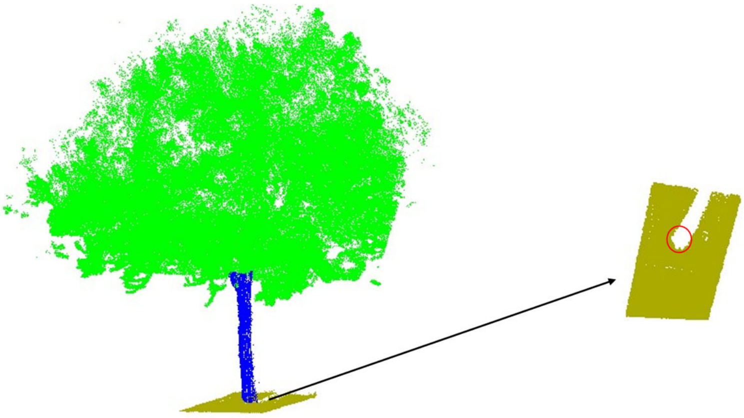

Figure 2. Bottom Center Fitting

Determining the Bottom Center: First, identify the ground point cloud corresponding to the street tree. Use a combination of the RANSAC and least squares algorithms to fit the bottom-most cross-section point cloud of the trunk, determining the 2D coordinates of the fitted circle center. Next, using the X and Y coordinates of the fitted circle center as the center, set a range threshold to identify and segment the approximate location of the tree bottom ground point cloud in the ground point cloud. Then, based on the identified ground point cloud, calculate the minimum Z value to determine the Z coordinate of the tree bottom center. Project the ground point cloud onto a 2D plane to obtain the X and Y coordinates of the tree bottom center, finally obtaining the 3D coordinates of the tree bottom center.

(2)Cross-Section Fitting: For trunk analysis and fitting, the finer the cross-section division, the better it restores the trunk's thickness. However, this increases the computational load, so a standard segmentation interval needs to be set to regulate cross-section segmentation.

Steps for Cross-Section Fitting: Based on the trunk height, determine the segmentation interval and number of segments for the cross-sections. For each cross-section, perform a 2D plane projection and use the RANSAC and least squares combination algorithm to fit the 2D coordinates (X, Y) of the circle center, and simultaneously obtain the fitted diameter of the cross-section. Restore the cross-section point cloud to the 3D space to obtain the height at the median thickness of the cross-section point cloud, which is taken as the Z value of the corresponding cross-section fitted circle center. Finally, summarize the data to obtain the complete fitting data of the trunk cross-sections, including the fitted circle center coordinates (X, Y, Z) for each cross-section.

2.3. Crown Fitting

The crown is one of the key parameters of street trees and plays an important role in analyzing their growth changes. The size of the crown affects the roadside environment and is a critical indicator for assessing tree growth and identifying tree species.

2.3.1. Crown Spread Fitting

The crown spread refers to the maximum width of the crown's lateral extension, i.e., the horizontal distance from the outermost edge of the crown to the opposite side. Crown spread is an important indicator for evaluating tree growth condition, crown health, and urban greenery coverage. The crown spread of street trees is typically defined as the diameter at the widest part of the crown, measuring from one outer edge to the opposite outer edge. This measurement reflects the tree's ability to expand into the surrounding space, which is crucial for predicting the tree's shading capacity and air purification abilities.

The crown point cloud of a street tree projected onto the horizontal plane (XOY plane) is approximately circular. Therefore, the least squares method is used to fit the crown projection point cloud, with the fitted diameter representing the crown spread.

2.3.2. Crown Volume Calculation

The crown is an irregular convex structure with gaps between branches, making accurate volume calculation challenging. Traditional methods consider the crown as an approximately regular geometric body for volume calculation, but these are often imprecise. The crown point cloud generated by laser scanners facilitates the observation of the internal structure of the crown, aiding in calculations. By processing the crown with horizontal slicing (as shown in Figure 3), it is possible to quickly discern the internal growth status of the crown, allowing for efficient and reliable volume calculation.

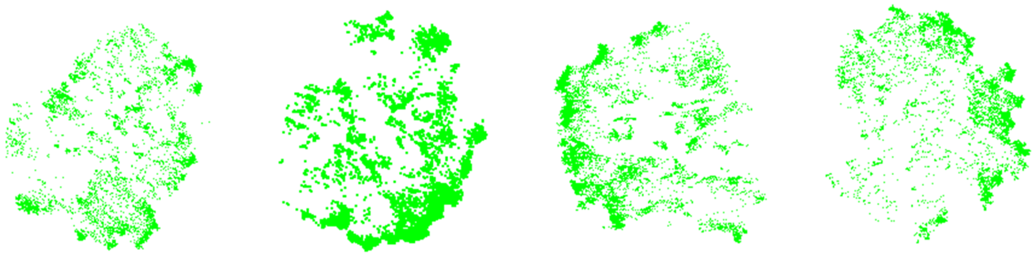

Figure 3. Crown Slicing

Calculating the crown volume is the most crucial step in studying the crown. Currently, several methods are available for calculating crown volume, including the voxel accumulation method, convex hull volume method, mathematical model fitting method, and direct volume calculation method. This paper employs the voxel accumulation method to calculate the crown volume. The crown point cloud data is divided into multiple 3D grid voxel units. For each voxel unit, it is checked whether it contains point cloud data. If it does, the volume of that unit is added to the total volume, thereby estimating the crown volume.

3. Dynamic Analysis of Street Trees

The dynamic analysis of street trees primarily involves observing changes in street trees over different time periods, including information updates, transplantation and replanting (as shown in Figure 4), pruning, felling, and growth changes. These dynamic changes require analyzing the multi-temporal parameters of street trees from various aspects, including bottom center coordinates (position coordinates), DBH, tree height, crown volume, crown spread, and trunk height.

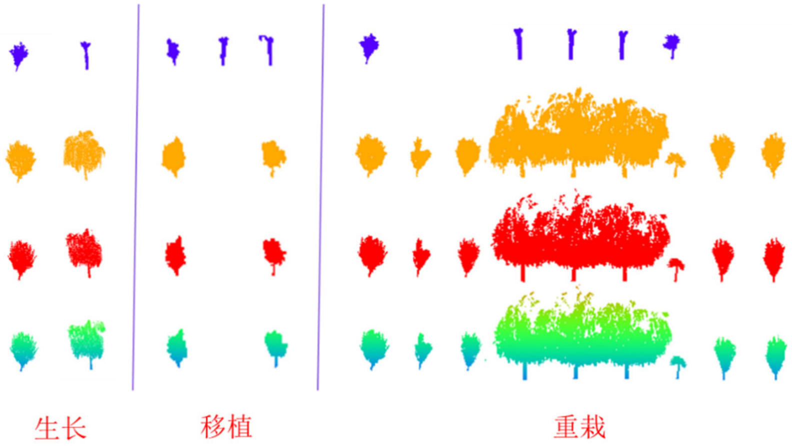

Figure 4. Typical Dynamic Changes of Street Trees

3.1. Information Update and Acquisition

Through precise fitting, obtain parameters such as DBH, crown volume, tree height, trunk height, bottom center coordinates, trunk cross-section center coordinates, and trunk growth posture of street trees. Dynamic analysis of street trees requires at least two periods of data, which is considerable in volume, necessitating the independent storage of each tree's information for easy retrieval and analysis. Subsequent data is stored based on the previous data. Due to LiDAR errors, the position of the same street tree in vehicle-mounted LiDAR point clouds from different periods may slightly vary, but generally not beyond a certain limit. Usually, the three-dimensional spatial coordinates (bottom center coordinates) of the first street tree serve as the reference center. A circular neighborhood is set within which the street tree is searched. If it exists, record all parameter information, and similarly obtain multi-period data for the street tree; if not, mark it as empty.

3.2. Transplantation and Replanting Analysis

3.2.1. Transplantation Analysis

Transplantation of street trees refers to relocating street trees that have grown for a period from their original location to another place, causing them to disappear from the original location. In 3D laser point clouds, this appears as having street tree point clouds in earlier periods but none in later periods. Analyzing the location information of street trees determines transplantation. If the parameter information of a street tree is empty in the later periods, it is considered transplanted.

3.2.2. Replanting Analysis

In LiDAR point clouds, determining street tree replanting mainly relies on changes in DBH, trunk height, and tree height. Replanting usually selects younger trees or new saplings similar or identical to the original species to ensure survival. The DBH of replanted trees should not exceed the original DBH, and tree height and trunk height should not exceed the original tree's height. Therefore, it is necessary to consider seasonal differences in multi-period data collection and city managers' operations. By comparing the DBH, tree height, and trunk height of street trees in later and earlier periods, if the DBH decreases or the tree height decreases, or the DBH increases significantly, the trunk structure line is extracted for secondary verification. If the trunk structure line changes significantly, it indicates replanting of the street tree.

3.3. Growth Status Analysis

Judgment of street tree crown pruning is primarily based on comparing the DBH with crown parameters, as follows:

(1) Increase in DBH: Indicates tree growth. If the crown size, tree height, and crown volume decrease, the crown may have been pruned, but the street tree grows normally. Compare multi-period parameters to assess the tree's growth status and update the current information with later data.

(2) Decrease in DBH: If the crown information decreases, extract trunk information and use the replanting judgment method to determine if it has been replanted without a change in location. If replanting has occurred, replace the original information with new tree parameters. If there are no significant changes in location and parameter information, an on-site inspection is necessary to determine if the street tree has pests, diseases, or has died.

4. Experiment and Results Analysis

To study the dynamic changes of street trees in road scenes, this experiment selected two areas, collecting six periods of data from 2016 to 2024 as multi-period analysis data. The point cloud of the experimental area is shown in Figure 5.

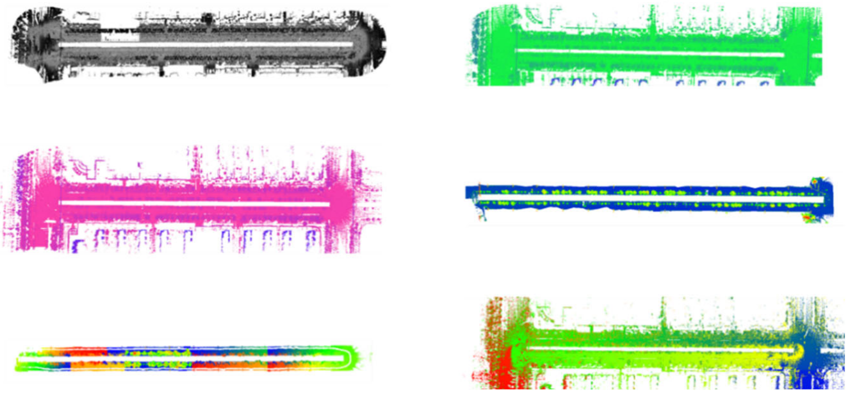

Figure 5. Original Point Clouds of Street Trees Across Six Periods

To improve the accuracy of DBH measurement, the average value of three actual measurements is used as the DBH measurement value, minimizing measurement error and making it closer to the true value. The calculated mean absolute error is 1.05 cm, with an average accuracy of 94.90%, a root mean square error of 1.703 cm, and a detection coefficient error of 0.015.

Using the position of the street trees in the first period as the center, a search radius of 0.8 meters is established. If corresponding street tree point clouds in the subsequent five periods are located within this search radius, they can preliminarily be unified as a group of comparative multi-period street tree data. This multi-period data set is analyzed to determine if the classification is correct. By comparing changes in the bottom center coordinates of street trees, six-period parameter data of street tree A and street tree B are selected for sample analysis. The locations of the multi-period point cloud data for trees A and B in the experimental area are shown in Figure 6.

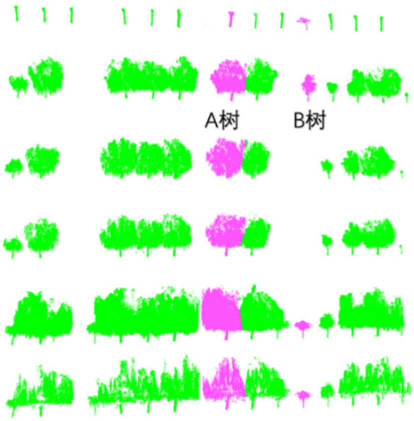

Figure 6. Spatial Positions of Trees A and B

Analysis reveals that for Tree A, the deviation of the bottom center 3D coordinates in the X and Y directions relative to the previous period is within the error range in each period, and the DBH values in each period do not decrease compared to the previous period. The changes in tree height may vary due to seasonal reasons of the collection dates, indicating that Tree A remains the same throughout the periods.

In contrast, Tree B has street tree point clouds in the first, second, fifth, and sixth periods, but lacks street tree data in the third period (January 2020) and fourth period (December 2020). The street tree point cloud reappears in the fifth period of 2023. Data shows that in the first and second periods, the X and Y deviations of Tree B's bottom center coordinates are minimal, and the DBH value increases from 8 cm to 12 cm. In the second and fifth periods, the Y direction difference of Tree B exceeds 1 meter, and the DBH value decreases from 12 cm to 9 cm. In the fifth and sixth periods, the bottom center X and Y errors return to normal, and the DBH value slightly increases. Therefore, it can be inferred that a sapling was planted in Tree B's location before 2016, grew until 2019, and was possibly transplanted due to disease or death, and another sapling was replanted before 2023.

In summary, through extensive experimental data analysis, a total of 97 sets of comparative data were generated from the six-period street tree point cloud data in the entire survey area. Among these, 63 street trees were found to be growing normally, 7 were transplanted, 12 were replanted, 12 were transplanted and then replanted, and 3 were replanted and then transplanted. Comparing the line graphs of crown volume and crown spread (Figures 4-8 and 4-9), it is found that the crown size of street trees in the second and sixth periods has decreased.

5. Conclusion

The combination of RANSAC and least squares algorithm proposed in this paper outperforms the traditional RANSAC algorithm in DBH fitting for street trees. By testing the fitting results with the detection algorithm, optimal fitting results are ensured. Although this algorithm meets the expected requirements for detailed fitting of tree trunks, it still has limitations: it performs poorly in fitting trunks with missing point clouds due to occlusions, especially when there is a large-scale loss of point clouds in the trunk section, resulting in low fitting accuracy.

Comprehensive analysis of multi-period data of street trees reveals that municipal authorities conducted overall pruning of street trees in the area during this period. This data dynamically recorded the growth changes of street trees from 2016 to 2024, which is significant for analyzing street trees in urban road scenes.

This paper innovatively proposes a comprehensive analysis method based on the correlation and weighting of various parameters in the analysis of street trees. The proposed method interrelates the extracted parameter information of street trees, conducting a comprehensive and multi-angle dynamic analysis. This approach effectively addresses issues of inadequate consideration and insufficient analysis in dynamic analysis of street trees, providing valuable reference for future dynamic analysis of surface features.

References

[1] Bulletin on the Status of Urban Construction in China, 2022 [S]. Ministry of Housing and Urban-Rural Development. 2023-10-13.

[2] Jiang, X. Real Estate Regulation According to Local Conditions, New-Type Urbanization Focused on People [N]. Guangdong Construction News, 2024-03-08(001).

[3] Yang, B., Liang, F., & Huang, R. Research Progress, Challenges, and Trends in 3D Laser Scanning Point Cloud Data Processing [J]. Journal of Geomatics, 2017, 46(10), 1509-1516.

[4] F.Monnier ,B.Vallet ,B.Soheilian.TREES DETECTION FROM LASER POINT CLOUDS ACQUIRED IN DENSE URBAN AREAS BY A MOBILE MAPPING SYSTEM[J]. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences,2012,I-3(1).

[5] Zhong R ,Wei J ,Su W ,et al.A method for extracting trees from vehicle-borne laser scanning data[J].Mathematical and Computer Modelling,2013,58(3-4):727-736.

[6] Yang, S., Li, Y., Li, K., et al. Extraction of Individual Trees Based on Vehicle-Mounted LiDAR Data [J]. Surveying and Mapping Engineering, 2014(8), 23-27.

[7] Zhang, X., Li, Y., Mao, J., et al. Fine Segmentation of Connected Street Trees in Vehicle-Mounted LiDAR Point Clouds [J]. Science of Surveying and Mapping,2016, 41(8), 111-115.

[8] Bu G ,Wang P .Adaptive circle-ellipse fitting method for estimating tree diameter based on single terrestrial laser scanning [J]. Journal of Applied Remote Sensing, 2016, 10(2): 026040-026040.

[9] Ye W ,Qian C ,Tang J ,et al.Improved 3D stem mapping method and elliptic hypothesis-based DBH estimation from terrestrial laser scanning data[J]. Remote Sensing, 2020, 12(3): 352

[10] Liu, L., Pang, Y., & Li, Z. Extraction of DBH and Tree Height of Individual Trees in Subtropical Forests Based on Ground-Based LiDAR [J]. Scientia Silvae Sinicae, 2016,52(02), 26-37.

[11] Adilson B, G M A T, Xinlian L, et al. Vertical Optical Scanning with Panoramic Vision for Tree Trunk Reconstruction. [J]. Sensors (Basel, Switzerland),2017,17(12):2791-2791.

[12] G. T ,H. M .ROADSIDE TREE EXTRACTION AND DIAMETER ESTIMATION WITH MMS LIDAR BY USING POINT-CLOUD IMAGE [J]. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2021,V-2-2021.

[13] Zhengnan Z ,Tiejun W ,K. A S ,et al.An improved area-based approach for estimating plot-level tree DBH from airborne LiDAR data[J].Forest Ecosystems,2023,10.

[14] Deng, Y., Wang, J., Liu, Q., et al. F-LS Algorithm for Extracting Tree DBH [J]. Remote Sensing Information, 202237 (05), 77-84.

[15] Fan, L., Liu, J., & Wang, J. Research on Tree DBH Extraction Algorithm Based on Minimum Variance Iterative Circle Fitting [J]. Journal of Northwest Forestry University,2016, 31(03), 215-220+227.

[16] Duanmu J ,Xing Y .Annular neighboring points distribution analysis: A novel PLS stem point cloud preprocessing algorithm for DBH estimation[J].Remote Sensing,2020,12(5).

[17] Liu C ,Xing Y ,Duanmu J ,et al.Evaluating different methods for estimating diameter at breast height from terrestrial laser scanning[J].Remote Sensing,2018,10(4):513.

[18] Kong J ,Ding X ,Liu J ,et al.New hybrid algorithms for estimating tree stem diameters at breast height using a two dimensional terrestrial laser scanner [J]. Sensors, 2015, 15(7): 15661-15683.

[19] Wang P ,Gan X ,Zhang Q ,et al.Analysis of Parameters for the Accurate and Fast Estimation of Tree Diameter at Breast Height Based on Simulated Point Cloud [J]. Remote Sensing, 2019,11(22): 2707-2707.

[20] Lei Y ,Jie W ,Xiaojun L ,et al.Comparison of numerical calculation methods for stem diameter retrieval using terrestrial laser data[J].Remote Sensing,2021,13(9):1780-1780.

[21] Jialong D ,Yanqiu X .Estimating diameter at breast height using personal laser scanning data based on stem surface nodes in polar coordinates[J].Remote Sensing Letters, 2020, 11(12): 1051-1059.

[22] Wu, H., Wang, X., & Liu, C. Automatic Extraction Method of Tree DBH Based on Forest Laser Point Clouds [J]. Journal of Tongji University (Natural Science Edition), 2022,50(07), 947-954.

[23] Luo J ,Zhang M ,Zhou X ,et al.Tree height and DBH growth model establishment of main tree species in wuling mountain small watershed[J].IOP Conference Series: Earth and Environmen-tal Science, 2018,108(4):042003-042003.

[24] Lin Y ,Jiang M.A new algorithm for MLS-based DBH mensuration and its preliminary validation in an urban boreal forest: Aiming at one cornerstone of allometry-based forest biometrics[J]. Remote Sensing,2018,10(5):749-749.

[25] Kuo L ,Yunhe L ,Bingzhang Z ,et al.Examining the role of UAV lidar data in improving tree volume calculation accuracy[J].Remote Sensing,2022,14(17):4410-4410.

[26] Dong, Y. Research on Extraction and Classification of Typical Objects in Road Scenes Using Vehicle-Mounted LiDAR Point Clouds [D]. Henan Polytechnic University.2019.

[27] Wang, P., Liu, R., Ma, X., et al. An Automatic Extraction Method for Pole Targets in Vehicle-Mounted Laser Point Clouds [J]. Journal of Wuhan University (Information Science Edition), 2020,45(07), 1035-1042.

[28] Li, P. Classification and Dynamic Analysis of Typical Pole-Like Objects in Roads Based on Vehicle-Mounted LiDAR Data [D]. Henan Polytechnic University.2020.