

# Method for Extracting Tree Diameter at Breast Height Based on Vehicle-Mounted LiDAR

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## Abstract

Addressing the issues of low fitting efficiency and precision in the process of fitting tree diameter at breast height (DBH) using vehicle-mounted LiDAR point clouds, this paper proposes an energy function model based on least squares roughness constraint weighting to compensate for fitting accuracy and improve the extraction method of tree DBH parameters. Through fitting and comparative analysis of tree DBH using the energy function on roads in the experimental area, the accuracy of DBH extraction has been significantly improved, with the mean absolute error (MAE) of road tree DBH being 1.70 cm and the root mean square error (RMSE) being 2.60 cm. The results indicate that working on only one side of the tree, namely the side visible from the road, is still feasible for approximating different DBH structural parameters using precise fitting.

## Keywords

Vehicle-borne LiDAR; Fitting; Roughness; Least Squares; DBH

## 1. Introduction

Roadside trees are an important part of the urban greening ecosystem. They not only reduce noise in the city but also purify the air quality, playing a crucial role in local climate regulation and ecological balance. Liu Luxia et al. utilized the Hough transform for diameter at breast height (DBH) fitting, generated point clouds from vertical optical flow images of a fisheye camera, and fitted the DBH [1]. Through the projection of point clouds on a plane and connecting adjacent points to form a wire frame model, they extracted vertically aligned circles to estimate the DBH of each tree [2]. Additionally, there are DBH fitting algorithms based on region segmentation [3]. The least squares quadratic screening method (F-LS), the minimum variance iterative algorithm for DBH fitting [4], the annular neighbor point distribution analysis (ANPDA) for DBH fitting [5], an evaluation of three commonly used DBH estimation algorithms (Hough transform, linear least squares circle fitting, and nonlinear least squares circle fitting), and the Levenberg-Marquardt method for

nonlinear optimization of the algebraic circle fitting algorithm in polar coordinates to obtain tree diameters [6] are also employed. The optimal model between tree height and DBH of major tree species is constructed [7], a conical geometric model is used to model tree trunks for DBH fitting[8], and the model between tree height and DBH is utilized to estimate the DBH of trees.

To enhance the precision of MLS breast height diameter (DBH) extraction, this paper introduces a weighted energy function model based on least squares roughness constraints. The primary research efforts of this paper are as follows: (1) proposing a roughness quantification analysis method based on the microscopic texture of individual tree bark surfaces; (2) integrating least squares with roughness constraints to propose a weighted energy function model based on roughness constraints for refined extraction of tree DBH, thereby minimizing the impact of outward deviations caused by the roughness of street trees on DBH extraction.

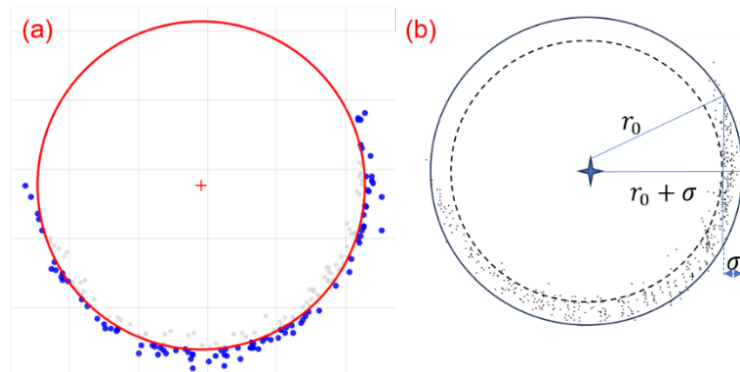
## 2. Energy function model based on least squares roughness constraint weighting

### 2.1. Least squares fitting

This method first obtains the center and radius of the point cloud set of 0.1m diameter breast height (DBH) cut segments based on the least squares method (LS). The least squares principle is calculated as per the formula(1).

$$R_{LS} = \sqrt{x_0^2 + y_0^2 - c} \quad (1)$$

Among them,  $R_{LS}$  represents the radius obtained through least squares fitting,  $(x_0, y_0)$  is the center of the circle after fitting with 0.1 DBH (Diameter at Breast Height) slices, and  $c$  denotes the constant term. Since the least squares method obtains the radius by minimizing the sum of squared errors, it essentially represents the mean value of the point cloud distribution. For rough bark surfaces (such as pine and willow), due to the presence of cracks (wave troughs), the mean value is significantly smaller than that of the outer bark. The roughness of the bark surface is not simply random noise, but rather possesses self-similar geometric characteristics.



**Figure 1.** Quantification of roughness residuals on bark surface

## 2.2. Roughness quantification analysis

The point cloud data of street trees obtained by vehicle-mounted LiDAR not only includes geometric position information of the tree trunk, but also implicitly contains microscopic texture features of the bark surface. Traditional trunk diameter at breast height (DBH) fitting algorithms, such as the least squares method and the RANSAC algorithm, usually assume that the trunk cross-section is an ideal circle. The Range value describes the maximum height of unit area  $R$ , which is calculated as the vertical distance between the highest and lowest points of the unit area. BHF is described as the average maximum height, which is the average of the continuous maximum heights of BHF calculated on a 0.1m trunk segment, as shown in the formula(2).

$$R_c = R_{LS} + \sigma \quad (2)$$

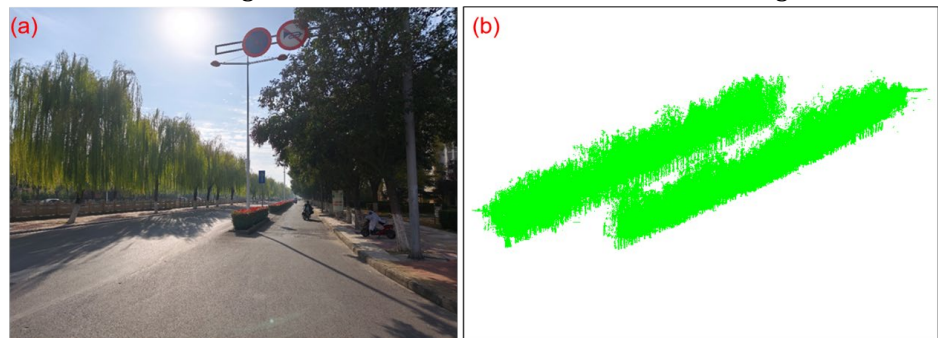
Where is the corrected radius,  $R_{LS}$  is the radius obtained through least squares fitting, and  $\sigma$  is the radial residual of all points. The obtained breast height diameter (DBH) follows the formula(3):

$$DBH = 2R_c = 2\sqrt{x_0^2 + y_0^2 - c} + 2\sqrt{\frac{1}{N}\sum_{i=1}^N (d_i)^2} \quad (3)$$

## 3. Experiment and Results

### 3.1. Study area and data

The study area is the urban road scene in Jiaozuo City, Henan Province (Figure 2). The linear road includes a median strip flanked by willows on both sides, with elm trees planted on the other two sides. It also includes typical pole-like ground objects such as road traffic signs and street lamps (Figure 2(a)(b)). The circular road includes two buildings and street trees such as ash, elm, and Wutong in the middle.



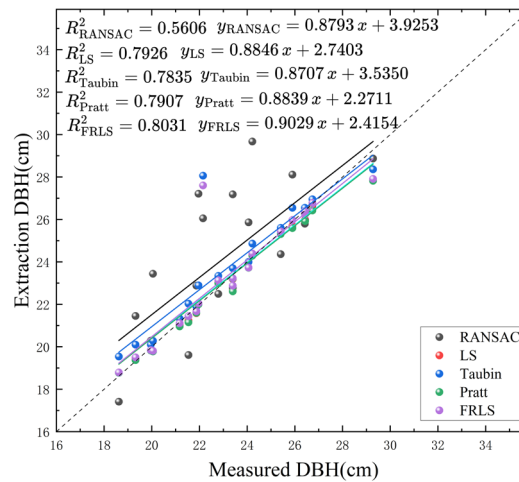
**Figure 2.** Research area. (a) Experimental road scene (b) Point cloud of road scene.

### 3.2. DBH extraction

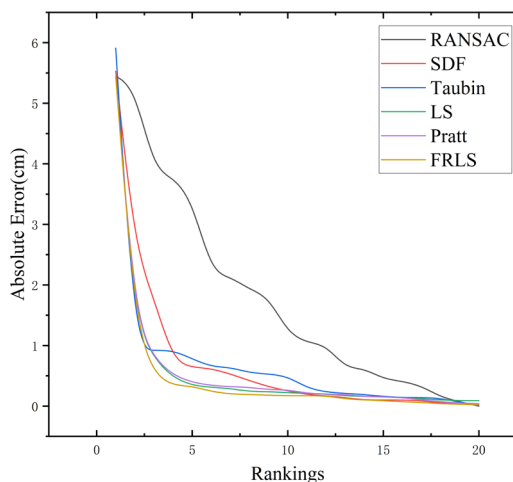
After importing the original point cloud into the 3D point cloud and mesh

processing software CloudCompare v2.13.beta, the built-in segmentation and cropping function of the software can be utilized to obtain the target point cloud and non-target point cloud, thereby acquiring the sample position point cloud data. In this paper, the road area shown in Figure 2 is selected as the experimental area and labeled as Road1. At the same time, the breast height diameter point cloud at a height of 1.25-1.35m of the street trees is extracted. The blue marking represents the extracted breast height diameter point cloud, as shown in Figure 2.

For Road 1, the root mean square error (RMSE) calculated by the RANSAC algorithm is 2.44cm, the mean absolute error (MAE) is 1.80cm, the average extracted breast height diameter is 24.36cm, and the relative accuracy (RA) is 89.50%. The RMSE calculated by the LS algorithm is 1.29cm, the MAE is 0.56cm, the average extracted breast height diameter is 23.29cm, and the relative accuracy is 94.45%. The root mean square error (RMSE) calculated by the FRLS algorithm is 1.27cm, the mean absolute error (MAE) is 0.52cm, the average extracted breast height diameter is 23.39cm, and the relative accuracy is 94.52%. The scatter plot of linear regression between the extracted DBH values and the measured values for Road 1, as well as the distribution plot of absolute errors in DBH, are shown in Figures 3 and 4.



**Figure 3.** Scatter plot of linear regression between DBH extraction values and measured values.



(a).Road 1 distribution of absolute errors in DBH

**Figure 4.** Distribution diagram of absolute error of DBH

## 4. Conclusion

In conclusion, this study demonstrates that it is feasible to obtain precise DBH data of trees over a large area of roads using mobile LiDAR by improving the least squares algorithm and correcting relevant data. The experimental results indicate that, compared to the LS and FRLS methods, the RANSAC method exhibits lower extraction accuracy. The weighted least squares approach, incorporating fractal dimension and roughness constraints proposed in this study, ensures that geometrically consistent data plays a dominant role in model fitting, thereby mitigating the impact of low-quality alignment data and noise on the accuracy of breast height diameter extraction.

## Acknowledgements

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