FDTLS_Tool User Manual

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1. Introduction

FDTLS_Tool is a free software developed by the RAMM research group (Radiation Modeling and Measurement, http://ramm.bnu.edu.cn/) of the Faculty of Geographical Science of Beijing Normal University. This software is a didactic product made only for pedagogic uses. It can be downloaded at https://github.com/CloudyCUG/FDTLS_Tool. For any information, question or bug report, please contact muxihan@bnu.edu.cn or lyk2@mail.bnu.edu.cn.

1.1 FDTLS_Tool usage

FDTLS_Tool is a software tool used to calculate the leaf area index (LAI) from terrestrial laser scanning (TLS) point cloud data or from fused TLS and unmanned aerial vehicle laser scanning (ULS) point cloud data. The software outputs the names of the point cloud files and their corresponding calculated LAI values to a text file named LAI_results.txt, which is located in the folder containing the user-selected point cloud files.

1.2 Hardware and software requirements

FDTLS_Tool is a software developed using PyCharm and has been verified to run properly on both Windows 10 and Windows 11 operating systems. It is provided as a compiled version and does not require PyCharm to be installed on the computer. FDTLS_Tool can be run directly without installation.

1.3 Copyright and limitations of responsibility

The FDTLS_Tool software and the accompanying documentation described herein are provided as freeware. The RAMM Research Group reserves the right to make changes to this software and its documentation at any time without prior notice. The RAMM Research Group shall not be held liable for any direct, consequential, or other damages arising from the use of the FDTLS_Tool software or its documentation. If the software is used in work leading to published intellectual property or scientific outputs, users are required to cite the corresponding article (Lai et al., 2026).

1.4 Theoretical background

The FDTLS_Tool software calculates LAI based on the FDTLS model proposed by Lai et al. (2026). This model establishes quantitative analytical expressions relating fractal dimension derived from canopy point clouds to canopy structural parameters such as LAI, canopy thickness, and equivalent leaf radius. The FDTLS model is independent of the Beer–Lambertian law and does not require projecting the canopy point cloud onto a two-dimensional plane. Moreover, it effectively accounts for the clumping distribution of leaves within the three-dimensional canopy space. A key feature of this model is its robustness to different leaf angle distribution (LAD) types. Thus, it can accurately estimate canopy LAI without needing explicit knowledge of the canopy's LAD.

2. Using FDTLS_Tool step by step

2.1 Choosing the point cloud file directory

The FDTLS_Tool software can process TLS point clouds as well as fused TLS and ULS point clouds. Users must first save the point cloud files in PLY format. Format conversion can be performed using the CloudCompare software. In the FDTLS_Tool interface, users can select the folder containing the point cloud files by clicking the "Browsing" button next to "Data folder path."

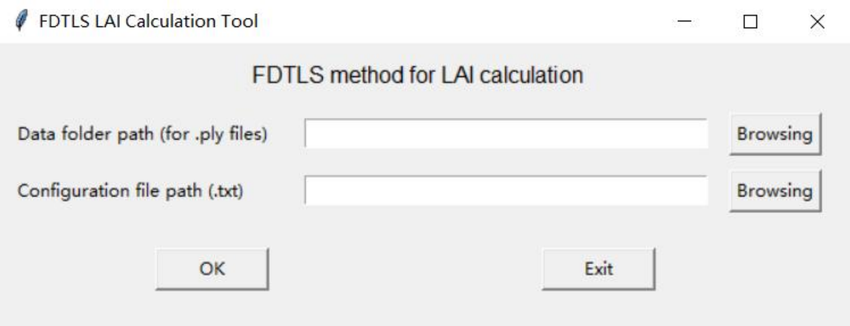

Fig. 1 FDTLS_Tool interface window.

The accuracy of the FDTLS method is affected by the completeness of the input point cloud. Therefore, the input should consist of multi-station merged point clouds. In dense canopies, when a visual inspection reveals noticeable gaps in the upper canopy points, the FDTLS method tends to produce some underestimation, with an RRMSE of approximately 16%. Integrating ULS and TLS point clouds can effectively mitigate this underestimation caused by missing upper canopy points. Lai et al. (2026) analyzed the relationship between FDTLS estimation bias and point cloud completeness using simulated point cloud data of two radiation transfer model intercomparison (RAMI) scenes (*i.e.*, Fig. 17 in their study).

2.2 Choosing the configuration file path

To calculate LAI from point cloud data, the FDTLS_Tool software requires users to provide several input parameters, including the point cloud file name, the corresponding X- and Y-axis ranges, leaf radius (in meters), woody-to-total area ratio, and the beam-effect correction factor. These parameters must be saved in a TXT file following the structure shown in Fig. 2.

```
merge-circle-10m.ply
0
10
0
10
0.05
0
1.02
merge-triangle-10m.ply
0
10
0
10
0.05
0
1.05
```

Fig. 2. Example of the Configuration File

Fig. 2 contains two example point cloud datasets. The meaning of each line in a dataset is explained as follows:

Line 1: The name of the point cloud file. Note that the file extension must be included.

Lines 2–5: The minimum X value, maximum X value, minimum Y value, and maximum Y value defining the X- and Y-axis ranges, respectively. Note that the X- and Y-axis ranges specified in the TXT file can be smaller than the actual extent of the point cloud file. In such cases, the LAI is calculated only within the range defined in the TXT file.

Line 6: Leaf radius, in meters. For example, a value of 0.05 indicates a leaf radius of 5 cm. For non-circular leaves, the equivalent leaf radius can be calculated from the measured leaf area S using $\sqrt{S/\pi}$.

Line 7: The woody-to-total area ratio of the plot (denoted as α). When the woody components of the canopy are considered, the FDTLS method estimates the plant area index (PAI). To obtain the LAI, PAI should be converted using the following equation (Chen et al. 1997):

$$\mathrm{LAI} = \mathrm{PAI}(1 - \alpha). \tag{1}$$

Line 8: The coefficient used to correct the laser beam divergence effect, referred to in this study as the *beam-effect correction factor*. The laser beams emitted by LiDAR sensors have a certain divergence angle. As the travel distance increases, the footprint size generated by beam divergence also increases. Even when the center of the laser beam does not directly hit a leaf, an echo may still be returned due to the footprint, leading to a fictitious increase in the estimated leaf surface area (see Fig. 7 in Mkaouar and Kallel (2024)). In this study, the correction method proposed by Mkaouar and Kallel (2024) was applied, in which the LAI estimated directly from the point cloud data (PCD) is divided by the ratio between the enlarged single-leaf area and the true single-leaf area. That is, the beam-effect correction factor is defined as the ratio between the enlarged single-leaf area and the true single-leaf area. The enlarged single-leaf area is obtained by fitting a leaf plane to the leaf point cloud (Fig. 3), whereas the true single-leaf area is measured using instruments such as the LI-3000C (LI-COR Inc., Lincoln, NE, USA).

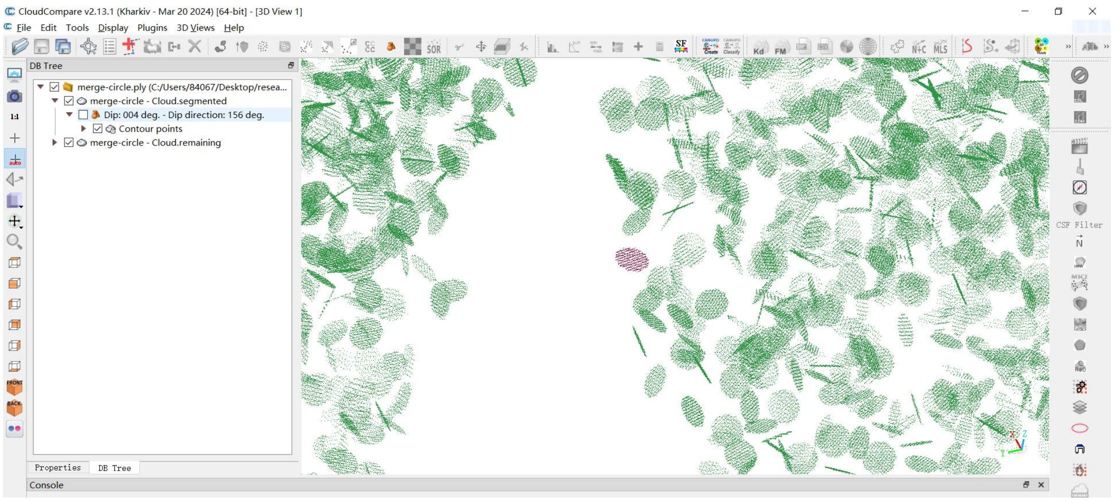

Fig. 3. Example of extracting a leaf point cloud in CloudCompare.

In Fig. 3, the red points represent an extracted leaf point cloud. After extracting the leaf point cloud, select it and click Tools in the toolbar. From the drop-down menu, select “2D polygon (facet)” to fit the leaf boundary. The fitted boundary points are shown as “Contour points” in the left panel of Fig. 3. Then, select “Contour points”, click Edit → Mesh → “Delaunay (2.5D best fitting plane)” to fit the leaf plane. This operation generates a file named “Contour points.mesh” (Fig. 4). Select this file, then click Edit → Mesh → Measure surface. The fitted plane area will be displayed in the CloudCompare console window, as shown in Fig. 5, where the area is $S = 0.008135$. The true area of this leaf is 0.0079. Therefore, the beam-effect correction factor for this leaf is 1.03.

This parameter is influenced by both the laser beam divergence of the scanner and the characteristic size of the leaves. When the beam divergence is 0.3 mrad (*e.g.*, RIEGL-VZ1000) or 0.35 mrad (*e.g.*, RIEGL-VZ400) and the leaf size is relatively large (*e.g.*, an equivalent leaf radius greater than 5 cm), the effect of beam divergence on LAI estimation can be neglected; therefore, this parameter can be set to 1. In contrast, for smaller leaves—particularly when the equivalent leaf radius is less than 3 cm—the impact of beam divergence on LAI estimation becomes significant. In such cases, it is recommended that the beam-effect correction factor be calculated following the procedure described above and applied to correct the results. For real forest canopies, multiple leaves can be selected within the canopy to calculate individual beam-effect correction factors. The mean value of these factors can then be used as the plot-scale beam-effect correction factor.

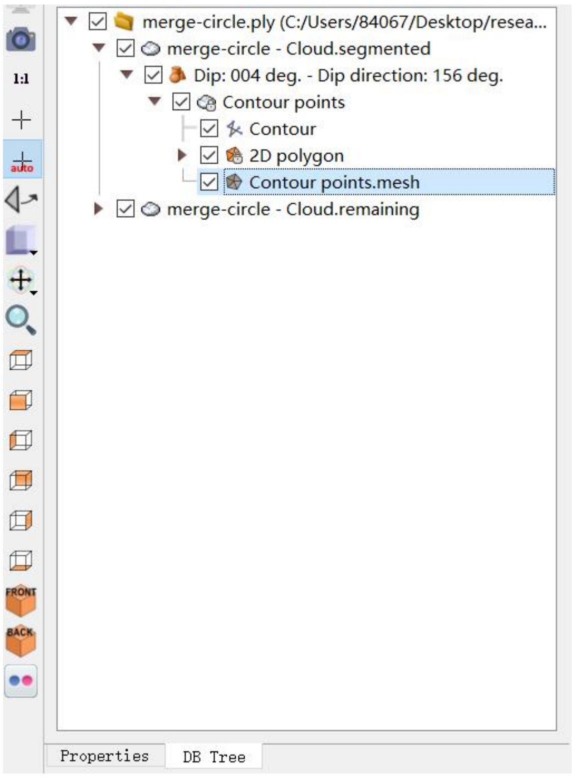

Fig. 4. Leaf plane fitted using CloudCompare.

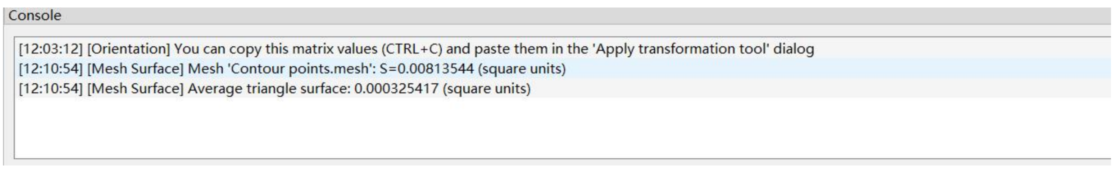

Fig. 5. Area of the fitted leaf plane calculated in CloudCompare.

2.3 Running FDTLS_Tool

After setting the point cloud file path and the configuration file path, click the OK button on the FDTLS_Tool interface to start the process. Once you click OK, a text file named LAI_results.txt will be generated in the folder containing the point cloud files. Upon completion, the results will be output to this text file, as shown in the figure below.

```
merge-circle-10m.ply:  LAI=2.599894361964706
merge-triangle-10m.ply:  LAI=2.7164533988571424
```

Fig. 6. Contents of the result file output by FDTLS_Tool

2.4 Sample data

Two example point cloud datasets (*i.e.*, merge-circle-10m and merge-triangle-10m) are provided in the sample data folder, along with their corresponding configuration data stored in a TXT file named Configuration. The true canopy LAI for both point clouds is 2.51, and the accurate leaf area for each leaf is 0.0079 m^2, corresponding to a leaf radius of 5 cm. Users can follow the steps described in Section 2.2 to extract parameters such as the beam-effect correction factor from the point cloud for LAI calculation.

3. Citation information

If the software is used in work leading to published intellectual property or scientific outputs, users are required to cite the following article:
Lai, Y., Mu, X., Hu, R., Xie, D., Zhou, G., Yan, G. (2026). Estimating the leaf area index from terrestrial laser scanning point cloud data with fractal theory. ISPRS Journal of Photogrammetry and Remote Sensing. Under review.

4. References

Chen, J.M., Rich, P.M., Gower, S.T., Norman, J.M., & Plummer, S. (1997). Leaf area index of boreal forests: Theory, techniques, and measurements. *Journal of Geophysical Research: Atmospheres, 102*, 29429-29443

Lai, Y., Mu, X., Hu, R., Xie, D., Zhou, G., Yan, G. (2026). Estimating the leaf area index from terrestrial laser scanning point cloud data with fractal theory. ISPRS Journal of

Photogrammetry and Remote Sensing. Under review.
Mkaouar, A., & Kallel, A. (2024). Leaf properties estimation enhancement over heterogeneous vegetation by correcting for terrestrial laser scanning beam divergence effect. *Remote sensing of environment, 302*, 113959