Stumpage Forestry Data Mining based on 3D Laser Point Cloud

Abstract. Terrestrial laser scanner (TLS) was used to obtain stumpage point cloud data. Firstly, we used the ball neighbourhood combining with a uniform grid method to represent the spatial topology construction of the point cloud, thereby reduced the amount of calculation. Secondly, we used Hough transform to calculate timber volume and abandoned branches and leaves interference according to different depth circular centers continuity. Thirdly through calculating the point cloud features, such as normal vector, curvature, bending, etc, then automatically located the secondary branches position; Finally, comparing with the really measurement trees parameters; the effectiveness of our proposed method is proved.


Keywords: Point cloud data, Forestry parameters, Computer analysis.
Słowa kluczowe: dane chmury punktów, współczynniki zalesienia, analiza komputerowa.

Introduction

The forest has an irreplaceable status in regulating the earth’s environment for human survival and slowing down global environmental degradation trend, forest mensuration and forestry information research become an important issue in recent years, how to solve the forest tree fine measurement and provide an effective way is the main task of forestry management. Traditional mechanical tree measurement tools have low efficiency, and obtained measuring data with single form and poor precision; Trees measurement using optical method will be influenced by the occlusion and illumination, it has strict requirements in image acquisition angle and accuracy camera parameters, although using ultrasonic sensor array for tree measurement can get three-dimensional lattice image data of tree canopy, but only obtain tree surface data and can’t get canopy internal structure information. Terrestrial Laser Scanner (TLS) using laser ranging principle, be able to record true three-dimensional information of the space objects. Many scholars have used this technology in recent years [1, 2, 3]. By means of laser scanner technology, we obtained real tree 3D point cloud data, and combined with the latest computer graphics and image theory to automatically extract forest parameters, then can describe the inherent laws of trees growth variation, and show the real biomass information by 3D visualization method.

We used Leica laser scanner to scan a stumpage in campus from three different viewpoints, and realized point-clouds data registration to obtain the complete 3D tree model. tree 3D point cloud data as shown in Fig. 1, as can be seen from the figure, the tree with extremely complex morphology, so how to automatically obtain key forest parameters from the complex three-dimensional model is a problem to be solved in this paper.

This article is committed to mining the stumpage important forest parameters from the TLS point cloud data, Firstly point cloud data topological structure based on the grid and sphere neighbourhood is introduced, and according to the Hough transform to obtain main stem section circle centers, then trees main skeleton is extracted; Secondly according to the point cloud data features, we achieve a rapid, accurate and automatic method to determine secondary branches positions. Finally compared with manual tagged results, experiments prove the effectiveness of our method.

Point cloud data topological structure

Tree’s model is belong to irregular complex objects, so tree’s 3D model presents an extremely complex morphology, coupled with multi-angle acquisition data registration, the final scan stumpage point cloud have huge amount of data without any topological relationship, so how to quickly establish the point cloud topology structure becomes the foundation of forestry analysis.

Existing point cloud space partition method includes octrees, k-d tree and grid method. The former two methods need complicated pre-treatment process, for trees cloud point data with different morphology, algorithm will become more complex. In this paper, we use the uniform grid method combined with the sphere neighbourhood to calculate the point cloud topology structure. For space scattered point cloud data, we first calculate the maximum and minimum coordinates values of all data points, then according to these values create a rectangular box parallel to the coordinate, then the box is divided into a series of small cubes (called grids) with a given length, then all data points are classified into these corresponding grids by point coordinate values.

For a given point cloud data $P$, a single point \( p_i, i = 1, 2, ..., n \) extrema on different coordinate axis are \( x_{\text{min}}, x_{\text{max}}, y_{\text{min}}, y_{\text{max}}, z_{\text{min}}, z_{\text{max}} \). According to the given length $L$, cloud points space is divided into $m$ grids, each grid point center is recorded as $c'$. 

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Grid information is stored by the two-dimensional array, each point is stored into the index array corresponding to the grid. When we search the point neighbourhood, we first determine which grid \( g_p \) that current point \( p \) belongs to, then record all points \( p_g \) in the grid \( g_p \) and its adjacent grids, and calculate the points \( r_p \) in spherical space with center \( p \) and radius \( r \), the intersection of \( g_p \) and \( r_p \) is neighbourhood points of \( p \). As shown in formula 2:

\[
(p_x - c'_x) \leq L \text{ and } (p_y - c'_y) \leq L \text{ and } (p_z - c'_z) \leq L \\
\sqrt{(p_x - p_x)^2 + (p_y - p_y)^2 + (p_z - p_z)^2} \leq r
\]

Where \( (p_x, p_y, p_z) \) represent current point neighbourhood coordinates.

For the complex morphology of main stem, we used Hough transform detection method, after the main stem is segmented according to the height, segmental main stem are taken projection on the Z axis. \( \tilde{P} = \{ F_i, i = 1, 2, ..., n \} \),

where \( F_i \) is projection function. By setting the circle radius and detection threshold, we take circle detection to the projection images, and then determine the main stem growth by corresponding circle factors, the specific test results are as follow:
where $z_1, z_2$ represent two contiguous different height, $(a_x, b_1), (a_x, b_2)$ represent the main stem centers of the two contiguous different height, according to the centers continuity, the absolute distance between these centers should be less than a threshold, the distance between the error detection circles centers should be greater than the threshold, then locations of the main stem centers are determined. Using the formula (4) we obtain the skeleton of main stem, and combined the radius $r$ to get the main stem three-dimensional model, just as shown in Fig. 5.

![Main stem skeleton consists by continuous circle centers](image)

$$M(p_i) = \sum_{j \in M(p_i)} \theta_{p_i,j}$$

where the $\theta_{p_i,j}$ value range is $[0, \pi]$. Taking summing operation of normal angles between one point with all of its neighbour points $M(p_i)$ will get the normal angle value:

$$w_p(p_i) = \sum_{j \in M(p_i)} \theta_{p_i,j}$$

normal angle value $w_p(p_i)$ shows the bending degree of the current data point $p_i$ and its nearby neighbour points, if the $w_p(p_i)$ value increase, the bending degree of the surface is larger, the data points $p_i$ neighbourhood is more likely feature area; Conversely, if the $w_p(p_i)$ value is less, the bending degree of the $p_i$ neighbourhood is smaller and model surface is more smooth, thus it is remotely possible that $p_i$ neighbourhood will be the feature area.

Trees point cloud data feature calculation

How to get stumpage forest parameters from these 3D point cloud data depend on the point cloud features calculation [5, 6]. Point cloud features including curvature, normal vector, and the angles between the normal, these important parameters represent the 3D point cloud changes. For the stumpage points' 3D model, the extrema of these parameters correspond to the location of the branches and knot, these characteristics calculation method are given below.

For point cloud data $P$, suppose the neighbour points of a given point $p_i$ is $p_{i_0}, p_{j_1}, \ldots, p_{k_0}$, construct covariance matrix $C_i$ constituted by $p_{i_0}, p_{j_1}, \ldots, p_{k_0}$, then calculate the matrix minimum eigenvalue corresponding to the eigenvector, the eigenvector is the $p_i$ normal vector, and according to the $p_i$ local areas change to estimate the curvature

$$C_i = \begin{bmatrix}
    [p_{i_0} - \vec{p}_i] & \cdots & [p_{k_0} - \vec{p}_i] \\
    \vdots & \ddots & \vdots \\
    [p_{k_0} - \vec{p}_i] & \cdots & [p_{i_0} - \vec{p}_i]
\end{bmatrix}
$$

where $C_i$ is third-order positive semi-definite symmetrical matrix, $\vec{p}_i$ is $p_i$ neighbour points center, calculate three eigenvalues $\lambda_1, \lambda_2, \lambda_3$ and the corresponding eigenvectors $e_1, e_2, e_3$ of the matrix $C_i$, eigenvalues arrange in ascending order, $\lambda_1 \leq \lambda_2 \leq \lambda_3$, $\lambda_1$ describe the variation of the surface along the normal direction, and the $p_i$ normal vector is $n_i = e_1$, then curvature $H_i$ estimation can be represented by the following formula:

$$H_i = \frac{\lambda_1}{(\lambda_1 + \lambda_2 + \lambda_3)}$$

The change of the angle between normal vectors can measure surfaces curve or flat degree, the normal direction is applied to 3D point cloud model in this paper, in order to judge one point whether is a feature point, suppose $p_i$ is any point in point cloud data $G$, $p_j$ is the neighbour point of $p_i$, their normal vector is respectively $n_{p_i}$ and $n_{p_j}$, the angle between the normal vector $p_i$ and $p_j$ can be expressed as: $\cos \theta_{p_i,p_j} = \frac{n_{p_i} \cdot n_{p_j}}{|n_{p_i} \times n_{p_j}|}$, where the $\theta_{p_i,p_j}$ value range is $[0, \pi]$. Taking summing operation of normal angles between one point with all of its neighbour points $M(p_i)$ will get the normal angle value:

$$w_n(p_i) = \sum_{j \in M(p_i)} \theta_{p_i,j}$$

normal angle value $w_n(p_i)$ shows the bending degree of the current data point $p_i$ and its nearby neighbour points, if the $w_n(p_i)$ value increase, the bending degree of the surface is larger, the data points $p_i$ neighbourhood is more likely feature area; Conversely, if the $w_n(p_i)$ value is less, the bending degree of the $p_i$ neighbourhood is smaller and model surface is more smooth, thus it is remotely possible that $p_i$ neighbourhood will be the feature area.

The data point $p_i$ parameters include: mean $w_n(p_i)$, curvature $H_i$ and normal angle value $w_n(p_i)$, then we define the data point $p_i$ feature as:

$$w(p_i) = \left( \frac{\lambda_1 H_i + w_n(p_i)}{\lambda_3 w_n(p_i)} \right)$$

Where $\lambda_i$ is curvature coefficient, $\lambda_1$ is distance coefficient.

These parameters reflect the regional variation and flatness, point cloud at branches are usually with greater curvature variation and unfixed normal vectors, thus, the calculated features is correspond to the branches location. Specific experiments as shown in Fig.6, as can be seen from the Fig. 6(a), the normal vectors of main stem cloud points are consistent with same direction and size, but normal vector at branches are different from each other, Fig. 6(b) is the calculation result of $w(p_i)$, where the great value of $w(p_i)$ are corresponding to the red branches location.

Experimental results

The trees radius and branching positions are calculated by our method, and compared with manual extraction results from Lecia TLS data, the corresponding results as shown in Fig.7, test accuracy is 92.3 %.
Fig. 6. Tree point cloud features detection
(a) Tree’s point cloud vector graph
(b) Calculation tree’s branches location
Fig. 7. Experimental comparison
(a) Manually extract main stem diameter from leica cyclone point data
(b) Main stems radius results comparison
(c) Branches position results comparison
Table 1. Results comparison
<table>
<thead>
<tr>
<th></th>
<th>main stem volume (square meters)</th>
<th>detection branches number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our method</td>
<td>1.148</td>
<td>28</td>
</tr>
<tr>
<td>Manual results</td>
<td>1.062</td>
<td>34</td>
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Conclusion
We research tree forestry parameters through the application of leica TLS, and combine with the computer graphics and iconography to automatically calculate tree volume and branches location, in comparison with manually obtain results, experimental analysis show that our method has a higher correct rate. In the future work we will do in-depth research on important forestry parameters such as leaf area index and canopy density.

REFERENCES

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