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Geometric shape fitting on simulated and TLS-based leaning tree-trunk point cloud for precision forestry measurements

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Abstract

Remote sensing and measurement methods have gained great importance in forest surveys, forest inventory, growth, and planning of assets in the last decade. In particular, it is important to obtain geometric parameters from dense point cloud data and estimate the diameter at breast height (DBH), which is a common parameter in forest inventory. In this way, "precision forestry" measurements come to the fore and leave traditional measurement methods behind. However, these processes are rather tedious and more complex than one might think. The accuracy of geometric estimations depends on the application of convenient methods. In estimating tree trunk diameters, 2D planar calculation of the diameter determinations of leaning trees is an important source of error. In order to eliminate this error, it is planned to prevent it with the robust principal components analysis (PCA) algorithm. For this purpose, the proposed methodology has been tested on simulation and real test datasets. The results show that the application of robust PCA algorithms prevents significant errors.

1. Introduction

The diameter of a tree at breast or breast height is one of the most important measurements made by forest surveyors and experts, and it is also commonly referred to as "DBH". Another important parameter is the tree height, which is important in calculating the wood volume. This way, forest inventory, and forest assets are calculated "precisely" with these correctly obtained parameters. A total evaluation is made with the number of trees in the stand with all these parameters.

DBH measurements are measured from the tree's outer bark at a point close to approximately breast height. Breast height measurement is generally made at 1.30 meters above the tree trunk. Ground extraction is also important in determining breast height, and it is a key parameter in measuring growth, volume, and forest wealth in different periods with DBH data evaluation. This parameter of breast height is a suitable technique for measuring a tree to facilitate field measurements.

In forest management and inventory studies, forest practitioners applied formulations based on DBH to calculate growth, volume, and yield tables based on this parameter. There are traditional and modern techniques that can be used to measure the diameter of a tree(Fan, Dong, Chen, & Chen, 2020). The most commonly used device is to go near trees and use calipers, tape measure, or rope (Mokros et al., 2018; Reddy, Jha, & Rajan, 2018). Although these techniques have been used as the most accurate techniques from the past to the present, non-contact measurement techniques have also been developed today. Image processing and point cloud methods have emerged as effective alternatives for calculating DBH (Gollob, Ritter, & Nothdurft, 2020a).

On the other hand, this study is research to determine DBH measurements to be obtained from point clouds in leaning trees. The study was presented as a test both on a simulated cylinder and on a real data set.

2. Method

The methodology applied for DBH extraction from point clouds was carried out in 2 stages. The first of these is creating a cylindrical model and bending this model on the X-axis of 10 degrees with five different rotations. In the second stage, a 10 cm section is taken between 1.25 and 1.35 m above the ground height, and the circle fitting process is applied. The same methodology was applied to terrestrial laser scanning data. After the principal component analysis (PCA) (Wold, Esbensen, & Geladi,

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1987) application, the rotation of the cylinder, which was converted into a point cloud, was determined, and the effect of this leaning on the fitting of a circle and its elimination was performed with the circle fitting process. PCA is one of the most widely used multivariate statistical methods in practice. It is used to reveal the variation among the data and the subsets of the variables. The major axes of P point clouds are defined with their associated magnitudes v (eigenvalues) and λ (eigenvectors) (Burt, Disney, Calders, & Goslee, 2018). PCA is used to determine the basic axes in point cloud data and detect components in the field of statistics. PCA is highly sensitive to outliers, commonly encountered in point clouds. Outliers are classical measures of variance that increase excessively, and because the principal components follow the directions of maximum variance, they cause increased errors by outliers. A robust version of PCA has been developed. In this way, the principal components are defined in a structure that will not be disturbed by outlier noises. As a result, PCs are computed with reliable data, leaving out unreliable data (Varmuza & Filzmoser, 2016).

All applications were carried out in the *R* program (Team, 2021), 3DReshaper (3DReshaper, 2020), and CloudCompare (Girardeau-Montaut, 2019) software. The proposed methodology is coded in the *R* program.

2.1. Cylinder forming and leaning

In forest measurements, some trees lean with different effects. The trunks of these trees, which should be perpendicular to the surface normal according to the topographical effect, can be leaning to the ground instead of perpendicular to the ground. In this case, the DBH 1.30 circle fitting process from the point clouds is incorrect. After removing the cylindrical trunk, the leaning of this cylindrical trunk should be corrected.

This situation was simulated with the 3DReshaper software program. It was produced as a cylindrical mesh model with a height of 3 m and a radius of 10 cm. The cylinder center is taken as (0,0,0). The mesh model is decomposed into point clouds at 1 cm intervals.

This cylindrical point cloud was produced in 5 copies with 10-degree inclinations around the X-axis (Fig.1).

2.2. Pre-processing point cloud

In order to determine the height of the cylinder point clouds from the ground, the ground plane was produced as a planar mesh model. In this way, the height of the tree trunk points from the ground can be taken. Since the bodies are assumed to be cylindrical, the noisy points must be filtered with the RANSAC algorithm (Schnabel, Wahl, & Klein, 2007), or a different noise removal algorithm can be used. After this stage, the point cloud section between 0.80 m and 1.80 m height values is taken on Z-axis, and the PCA algorithm is applied in this section. After the orientations are determined, the next step is the geometric parameter fitting phase.

2.3. Circle Fitting (Späth)

In order to extract the geometric parameters from the point clouds, the circle fitting process suggested by the Spath algorithm (Späth, 1996) was performed on the PCA de-rotation point clouds. X and Y coordinate information in point clouds are extracted from the *las* file, and a planar 2D circle fitting is performed. The fitting process in the planar and parametric form given below is performed in the given point clouds.

$$x = a + r\cos z \qquad y = b + r\sin z \tag{1}$$

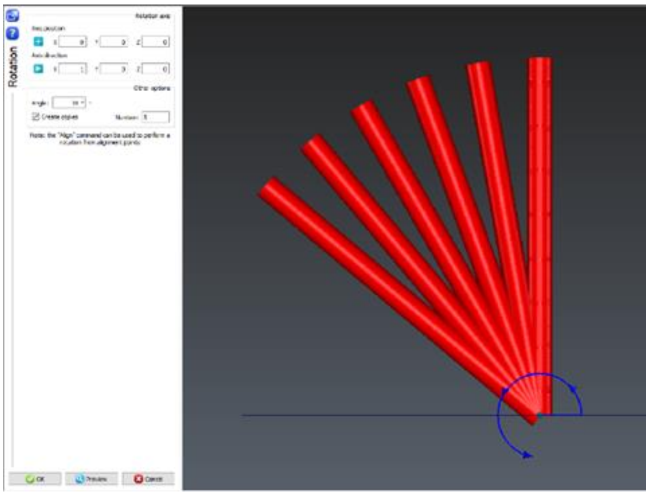

Figure 1. Cylinder forming and leaning

The minimization function of the errors with the sum of the total orthogonal distances is applied. The following function is used for this.

$$S(a,b,r,z_{1-n}) = \sum_{k=1}^{n} \begin{bmatrix} (y_k - b - r\sin z_k)^2 + \\ (x_k - a - r\cos z_k)^2 \end{bmatrix} \tag{2}$$

where (a, b) represents the center coordinates of the circle, r represents the circle's radius, and z values represent the center angle values. First, z is eliminated in the circle model and put into a non-parametric equation. Moreover, it transforms into the following form.

$$(x-a)^2 + (y-b)^2 = r^2 \qquad S(a,b,r) = \sum_{k=1}^{n} (\sqrt{(x_k - a)^2 + (y_k - b)^2 - r})^2 \tag{3}$$

All the calculations mentioned above have been implemented using the R *conicfit* package (Gama & Chernov, 2015).

3. Results

Radius values were obtained after PCA and Robust PCA application with circle fitting algorithms obtained at five angles and perpendicular to an original ground. The actual cylinder radius value is 10 cm. Fitting leaning cross-section values are named Raw data, PCA, and

Robust PCA. The original cross-section and curvature values of 10 and 50 degrees are called c0-c5. The circle fitting to c0, c3, and c5 data is shown in Fig.2.

Table 1. Descriptive statistics of circle fitting results on the simulated cylinder dataset

Statistics	Raw	PCA	Robust PCA
Mean [m]	0.1799	0.0999	0.1002
Median [m]	0.0871	0.0003	0.0003
Sd [m]	0.1553	0.0999	0.1001

In terms of descriptive statistical values, fitting a circle to the raw data yields very erroneous results (Table 1).

PCA and Robust PCA, on the other hand, provided high accuracy in tenths of a millimeter for both methods on data that has been de-skewed. The deviation values are quite low. However, it should not be forgotten that this is a perfectly cylindrical data produced by simulation, and there are point clouds from every angle to form the circle (Fig. 2). In practice, it is obvious that such data is not very smooth.

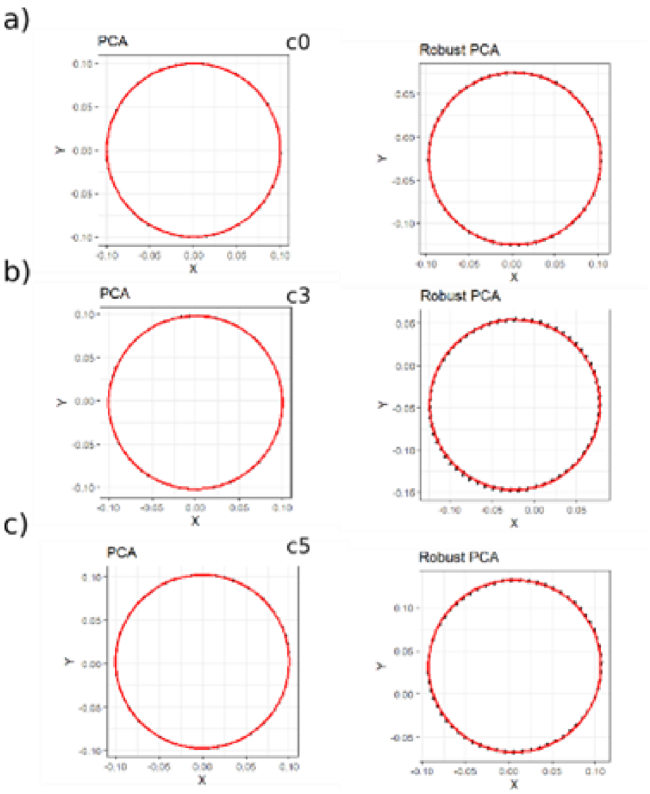

Figure 2. c0, c3, and c5 dataset circle fitting results at 1.25 m and 1.35 m

According to Fig.3, while PCA and Robust PCA methods produce results close to each other for all kinds of data, in the application of the circle fitting algorithm without using any leaning correction, the error rates increase linearly as the angles increase.

In this research, terrestrial laser scanner (TLS)-based point clouds obtained from the real forest were analyzed in addition to the simulation dataset. The laser scanning device used is a static terrestrial laser scanner (TLS) (Focus3D X330, Faro Technologies Inc., Lake Mary, FL, USA) (Gollob, Ritter, & Nothdurft, 2020b).

As shown in Fig. 4, the tree trunk was extracted from the point clouds. This data showed the importance of the Robust PCA application as it does not contain point clouds in every aspect like simulation data.

According to the reference dataset of the test data owners, the DBH value of this tree, which is in the eighth plot region and tree id 80, was obtained as 20 cm in the field. In addition, it has also been investigated to what extent the circle fitting process would be affected if it was a leaning tree.

Table 2. TLS point cloud data single-tree circle fitting and geometric results of radius

DBH	Reference	Raw	PCA	Robust PCA
R [m]	0.1	0.0813	0.0967	0.1019

In TLS-based point cloud sections, the DBH value on a single tree was measured as 0.1 m in diameter and 0.2 m in the field as a reference (Table 2). The proposed methodology used a geometric estimation with a deviation of 1.9 millimeters, which means a relative difference of 1%. It has been shown that the proposed method achieves more relevant results as Robust compared to other raw and normal PCA implementations (Fig. 5).

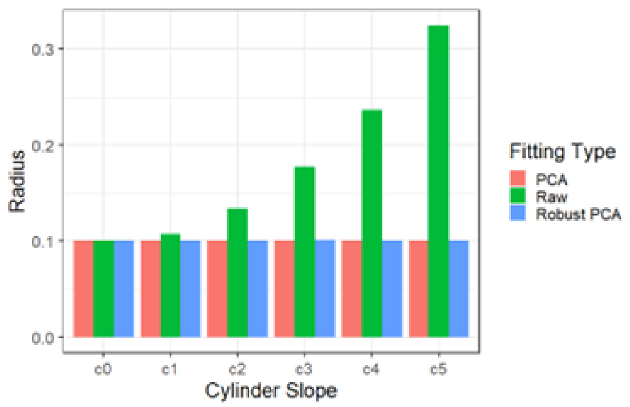

Figure 3. Fitting results of the three different methods on original and five leaned data

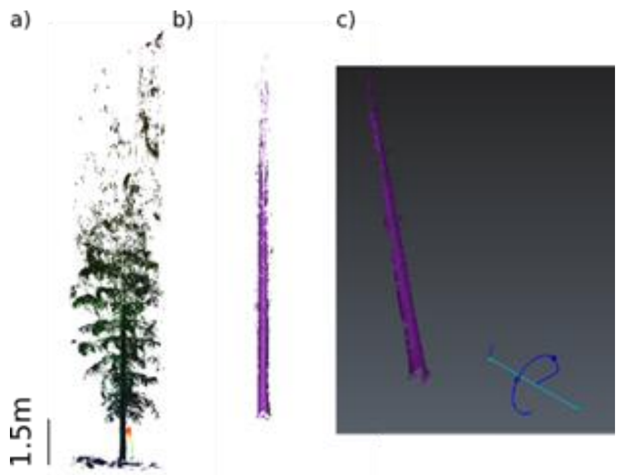

Figure 4. A manually cropped tree from TLS data, a) all point cloud data with surface normals calculated, b) extraction of the cylindrical body structure according to the RANSAC algorithm, c) trunk with 10 degrees inclination in the X-axis

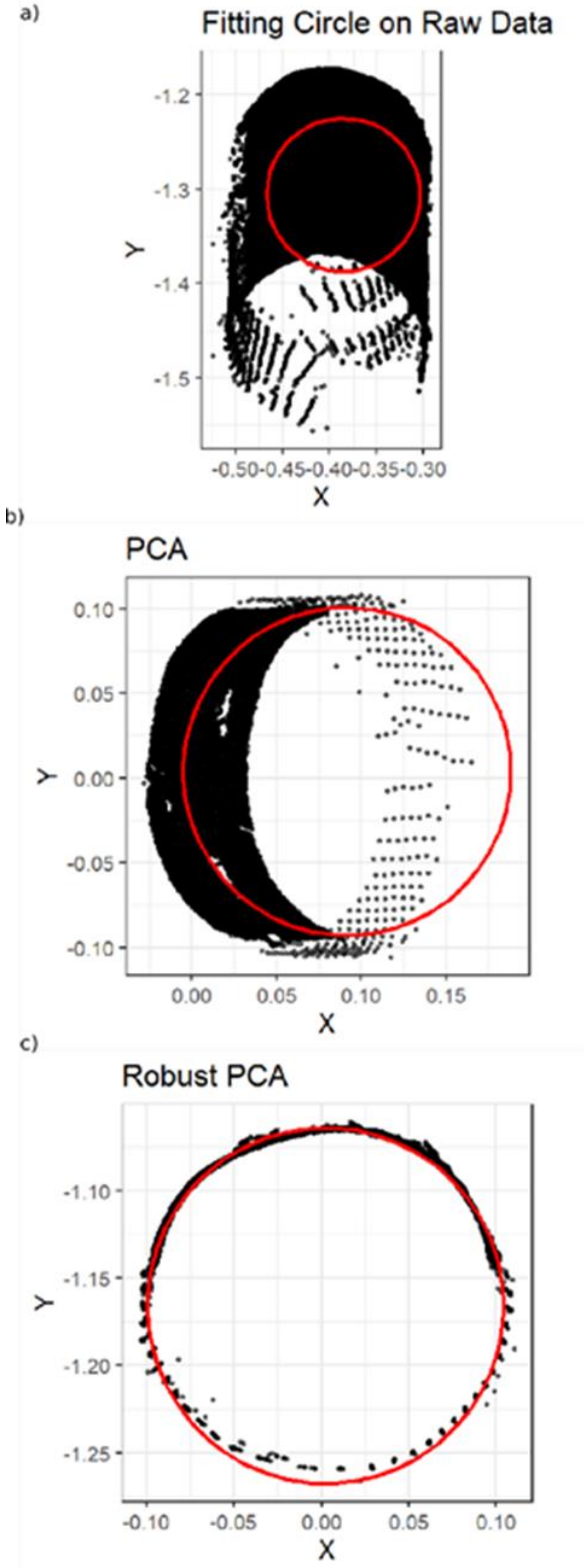

Figure 5. Single station TLS-based trunk point cloud circle fitting results a) raw data fitting, b) PCA rotated point cloud fitting, c) robust PCA based circle fitting

4. Discussion

In this study, circle fitting processes are complete for a single tree, and an important step is mandatory for forestry measurements. However, the study was carried out on the point cloud, which can be considered clear and very good, and based on a single tree. These methods also have certain limitations in real forest inventory measurements. Using the cylindrical and parametric model and TLS data used in this study, calculations were made on the trunk model with high accuracy on a noiseless stem. However, obtaining such high accuracy in hand-held laser scanners or noisy tree trunks is among the high possibilities, depending on the data structure. In addition, the complexity of forest structures, difficulties that may be encountered in individual tree detection, double trunk trees, etc., can be challenging. In this case, applying the proposed methodology to "easy" measurement point cloud data on a single tree basis and where the trunk points can be separated from the branches and leaves means that there may be limitations when faced with the mentioned situations.

In geometric parameter estimation, the proposed methodology was able to detect with high accuracy by providing flexibility in point cloud data that do not represent full circles, which are frequently encountered in TLS-based point clouds. Especially in single station scanning applications in TLS data, there are deficiencies in the point clouds of trees at certain ratios and directions. Since the proposed methodology uses the Späth algorithm, a geometric circle fitting algorithm, it gives better results than algebraic algorithms. It evaluates all point cloud data of the body in the DBH estimation. In this way, when the pre-processed data is used, it achieves successful results in estimating the DBH parameters of the trees.

5. Conclusion

This study is aimed to extract DBH from point clouds, which is common use in forest parameters. The application of the robust PCA method to evaluate and eliminate errors in the DBH fitting process that occurs in the leaned trees in DBH extraction has ensured that this error is minimized. The proposed methodology has been tried to make DBH measurements caused by tree slant, which can be encountered frequently in forest measurements and be used in a more "precision" forestry measurement. The study has two different test data; It has been tested on the simulated cylinder and TLS-based data, with significant success.

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