Tree diameter estimation using laser scanner

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Abstract

Accurate vehicle localization in forest environments is still an unresolved problem. GPS has obvious limitations in dense forest, and has to be mixed with other techniques to provide satisfying solutions. One possible way is to localize the vehicle relative to trees detected around the vehicle. The first step to implement this method is is to find reliable methods to detect trees, and also to match them to maps. The reliability of this matching operation is improved by accurate estimations of tree diameter. In this paper we evaluate a number of existing algorithms for detection of trees and estimation of tree diameter. Three new algorithms are also suggested. All algorithms were evaluated in field experiments at three different locations with varying tree trunk visibility. The results show that one of the existing algorithms is clearly less reliable than the other two. Noticeable is that the existing algorithms often overestimate tree trunk diameter. The new algorithms mostly underestimate, but are most accurate in some situations.

1 Introduction

This paper presents an algorithm for identifying trees in a 2D laser scan [6, 2] and evaluates six different trunk diameter estimations; three existing [2, 4, 5] and three methods developed during this work. To evaluate these six different methods and the tree identification algorithms, an experiment was done in a forest nearby Örträsk, Sweden (approximately 64° 10´ N, 19° 4´ E) as explained in the next section.

Figure 1: The laser scanner mounted on top of the cabin of a Valmet 931 harvester from Sveaskog. Photo: Ola Lindroos.

2 Materials and methods

For this experiment a SICK LMS 221 laser scanner was used. The laser scanner's angular resolution is 0.25°, field of view 100°, and has a measurement range up to 80 m with a measurement accuracy of ±3.5 cm. Each laser beam has a width of 0.8° (ca. 14 cm at 10 m range). The laser scanner and a GPS were mounted on top of a wood harvester cabin (see Figure1) ca 4 m above ground. The roll and pitch angel of the laser scanner were approximatively level to the cabin but the yaw angel is unknown since we could not measure this.

The laser scanner measurements took place on three different positions (called A, B1, and B2) in the same forest, along a slope (around 8° incline, with the top towards northeast). Figure 2 shows the view from the three different positions. Position A was located at the bottom of the slope, with the laser scanner pointing towards the top. The trees here had many needles and branches. The second position, B1, was higher up along the slope than position A, with the laser pointing towards the top. This position had the most visible tree trunks, with less branches and needles. The last position, B2, was the same as B1, but with the laser scanner pointing down towards Position A. Here, trees both with and without leaves, needles and branches were visible. A map of the three positions and their respective viewing angle can be seen in Figure 3.

For all trees, the diameter, the distance between laser scanner and trees, and

(a) Position A

(b) Position B1

(c) Position B2

Figure 2: View of the three different positions

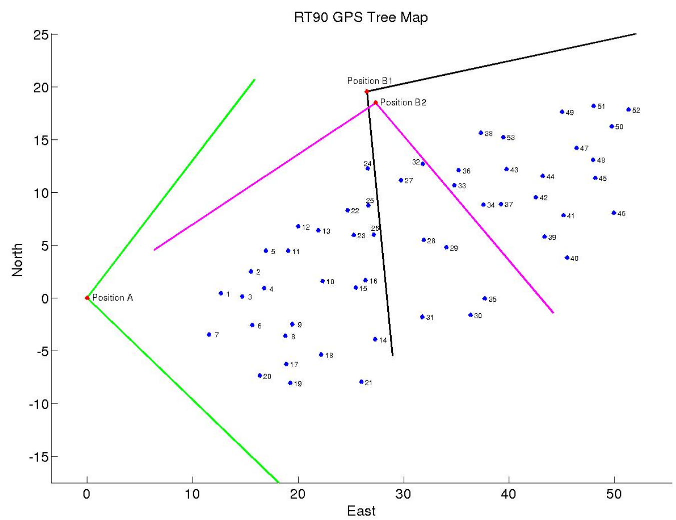


Figure 3: RT90 GPS tree map solution where the blue dots represents 53 trees and the three laser scanner positions are red dots. At each position, two lines show the laser scanner's field of view.

distance between trees were measured. For each tree, the distance to at least two adjacent trees was measured. This information was collected manually from the small forest with 53 trees and a manual draft tree map was created. Since the manual map did not have enough precision, the GPS position of each tree stump was measured at a later time when trees had been harvested. The resulting map can be seen in Figure3.

3 Tree identification

One of the problems with identifying trees in a laser scan is that only a few laser beams hit every tree. At 10 m range the space between two laser beams is ca. 4.5 cm with 0.25° resolution, which means that a tree with 20 cm diameter is hit by four beams. The laser scanner could also hit leaves, needles, or branches, making it even more difficult to identify trees.

For identifying trees, we used an algorithm from Jutila et al. (2007) [2] with slight modifications. To identify trees in a laser scan, the first thing to do is to cluster laser points. The tree clustering algorithm has two different parts. The first part creates a cluster of laser points close to each other, i.e. $\| r_i - r_{i-1} \| < \Delta R_{max}$ [2, 6], where r_i is the range of the i:th measurement and ΔR_{max} is the threshold for the maximum allowed distance between two points. The second part of the algorithm validates each cluster with the following five rules:

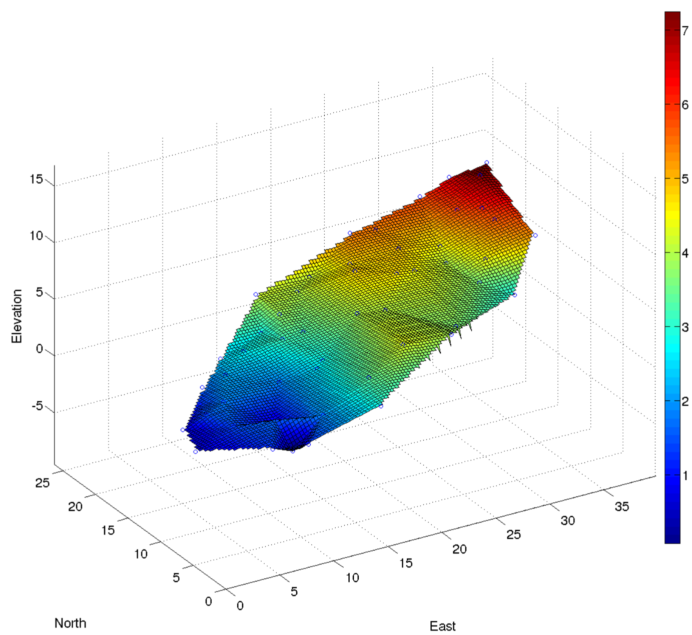


Figure 4: 3D representation of the tree map shown in Figure 3. De small blue circles represents the same 53 trees as in Figure 3.

1. The number points in the cluster has to be greater than two.
2. The curvature has to be greater than or equal to zero ($curv \geq 0$, see equation 2).
3. The diameter, calculated by "Circle Fit" algorithm (see Section 4.4), from the cluster has to be between 15 and 80 cm.
4. The "Circle Fit" max error has to be less than 0.15.
5. The range (in this case the height) of the cluster has to be greater than 0.08.

The curvature for each point is calculated by [2]:

$$c_i = r_{i-1} - 2r_i + r_{i+1}. \tag{1}$$

The curvature for the whole cluster is calculated using the curvature for each point c_i:

$$curv = \left(\sum_{i=1}^{n-1} c_i\right) / \left((n-1) \cdot r_{middle}^2\right) \tag{2}$$

where r_{middle} is the minimum measured range of the cluster and n is the number of points in the cluster.

To filter out branches and needles, different techniques were used. One was to look at the standard deviation from several consecutive scans, disregarding points with too high standard deviations. The idea is that a beam that hits a needle should miss it some times, and thereby increasing the noise in that position. Using the median and mean values respectively of several scans was also tested to filter out noise in the measurements. As described above, the tree identification algorithm depends, among other things, on tree diameter estimation methods. The better the diameter estimation is, the better the size of the tree cluster can be determined. Section 4 describes six different methods for estimating diameter.

4 Trunk diameter estimation methods

This Section describes six different methods for trunk diameter estimation. "Two triangle diameter estimation" (TDE) [2], "Diameter estimation with resolution of the laser scanner and the two outer points" (DER) [4], and "Circle Fit" (CF) [5] are existing tree diameter estimation methods. "Two triangle trunk estimation with two outer points adjusted" (TDEA), "Circle Fit with two outer points adjusted" (CFTA), and "Circle Fit with all points adjusted" (CFAA) are methods modified by us.

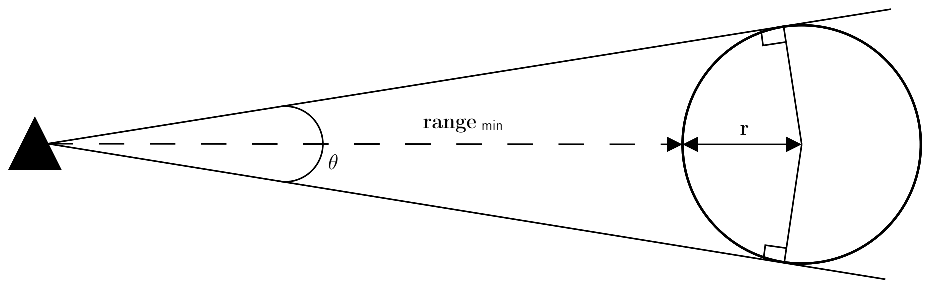


Figure 5: Tree trunk diameter calculation using two right-angled triangles and the shortest range of the tree cluster (from [2]).

4.1 Two triangle diameter estimation (TDE)

This approach for calculating the tree trunk diameter d uses the outer points and the shortest range (r_{middle}) of the tree cluster. The angle θ is calculated using the two outer points of the tree cluster [2], see Figure 5:

$$d = 2r_{middle} \cdot sin(\theta/2)/(1 - sin(\theta/2)). \tag{3}$$

4.2 Diameter estimation with resolution of the laser scanner and the two outer points (DER)

This method uses the first (r_1) and the last (r_n) cluster points, the number of cluster points, and the resolution of the laser scanner to estimate the trunk diameter d [4]:

$$d = (n - 1) \cdot \triangle\beta \cdot (r_1 + r_n)/2 \tag{4}$$

where:

n	is the number of cluster points
$\Delta\beta$	is the resolution of the laser scanner

4.3 Two triangle trunk estimation with two outer points adjusted (TDEA)

In this approach the trunk diameter is calculated with the TDE described in Section 4.1. The only difference is that the two outer points of the tree cluster is adjusted for the laser beam width (with 0.27°).

4.4 Circle Fit (CF)

Another approach for estimating a trunk diameter is a Circle Fit algorithm in a x,y plane. The Circle Fit algorithm tries to find the circle that best fits a given set of measured (x,y) pairs, see Figure 6. The algorithm outcome is a circle

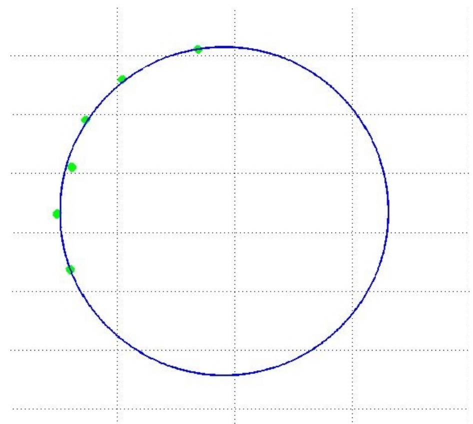


Figure 6: The green points represents a tree cluster and the blue circle is calculated with the CF algorithm.

with known radius R and center point (x_c, y_c) (i.e. finding x_c, y_c, R such that $(x - x_c)^2 + (y - y_c)^2 = R^2$).

4.5 Circle Fit with two outer points adjusted (CFTA)

This diameter estimation method uses CF for calculating the trunk diameter where the two outermost points of the tree cluster are adjusted for the laser beam width (with 0.27°). Figure 7 shows a tree cluster with green dots and the adjusted points with red crosses. The blue circle is created with the adjusted points from Circle Fit (see Section 4.4).

4.6 Circle Fit with all points adjusted (CFAA)

The last diameter estimation uses CF for calculating trunk diameter where all tree cluster points have been adjusted for the laser beam width (with 0.27°). Figure 8 shows a tree cluster represented by green dots and the adjusted points represented by black dots. The blue circle is created with CFAA (see Section 4.4).

5 Results

Table 1 presents the mean error value in percent and centimeters, and standard deviation or for all six tree trunk estimation methods for all three measured positions. In total, 19 trees were matched in the three positions with an average diameter of 28.3 cm. To see if the error is dependent on the distance to a tree, three different tree trunks was measured indoor on different distances (5-20 m with 1 m step). The results where mixed; CF is very sensitive to noise in the

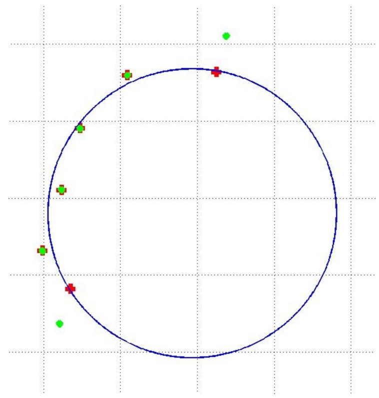


Figure 7: The green points represents a tree cluster, and the red points the tree cluster where the two outer points are adjusted. The large blue circle is calculated using the CFTA algorithm.

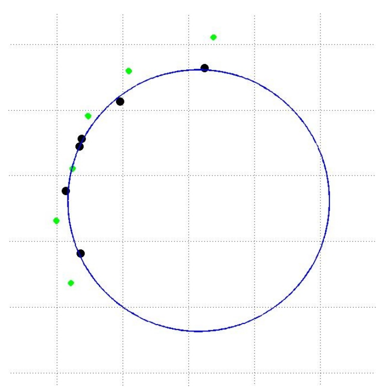


Figure 8: The green points is a tree cluster, the black circles are the tree cluster where the all points are adjusted, and the big blue circle is calculated using CFAA.

	Error [%]	Error [cm]	Std dev [cm]
TDE	58.2	11.8	13.7
DER	57.7	11.7	13.7
TDEA	42.3	9.1	12.6
CF	87.3	18.2	11.7
CFTA	53.2	10.3	16.2
CFAA	53.8	10.8	15.2

Table 1: The mean error in percent and centimeters, and standard deviation for for all 19 matched trees for each of the six estimation methods.

positions given by the laser scanner and thereby quite noisy, but the error generally grows larger with increased distance. TDE and DER gives approximately the same error regardless of the distance, while CFTA, CFTAA, and TDEA underestimates the trunk diameter more with increasing distance. In the indoor test, CFTA, CFTAA, and TDEA underestimates the trunk diameter while the other three overestimates it.

5.1 Position A

At position A, the tree identification algorithm identified five trees but one was a false positive (i.e the cluster did not match a real tree). At this position the clusters varied, the better the cluster was (i.e if no branches were disturbing) the better the methods work. As can be seen in Figure 9, tree 2 has a very large error for all methods. The reason is that the tree cluster contains not only the tree trunk but also parts of branches and needles as can be seen in Figure 10.

5.2 Position B1

At position B1 the tree identification algorithm identified eight trees, all of them matching real trees. In general it seems as if the CF, TDE, and DER overestimates the tree trunk diameter, as seen in Figure 11. The methods which compensate for the spot diameter underestimates the tree trunk diameter. Trees 2 and 7 have large errors for all diameter estimation methods. The reason is that the tree cluster consists not only of the tree trunk, but also part of a branch as can be seen in Figure 12. For this position the most stable tree trunk estimation method is the TDEA.

5.3 Position B2

The tree identification algorithm identified four trees at position B2, all of them matching real trees. In general, the tree trunk estimation method CF overestimates the tree trunk diameters at this position, as seen in Figure 13. The estimation method CFAA underestimates the tree trunk diameters. Figure 14 shows tree No. 2. This is the same tree as in Figure 12a, but from a this view the error is lower for all methods.

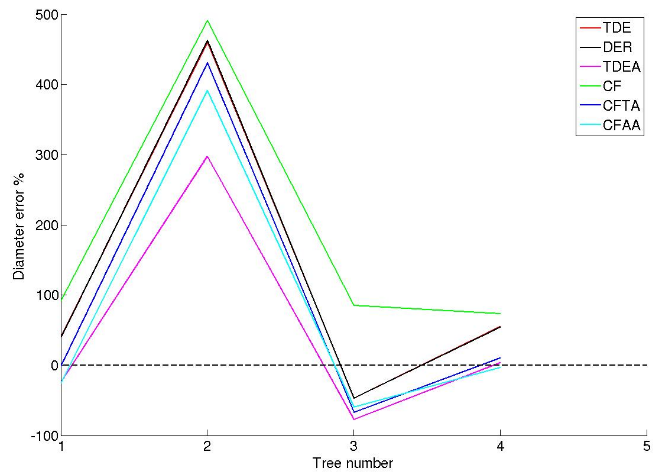


Figure 9: Diameter error results from Position A for all six diameter estimation methods (see Section 4) Tree No. 5 is a false positive and therefore not shown.

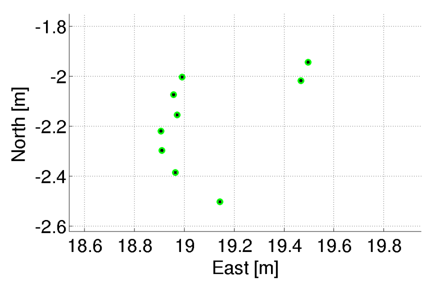


Figure 10: All points belonging to the tree cluster for tree No. 2 in Figure 9. It has a large diameter estimation error due to that a branch or some needles becomes part of the tree cluster (seen in the upper right part of the figure).

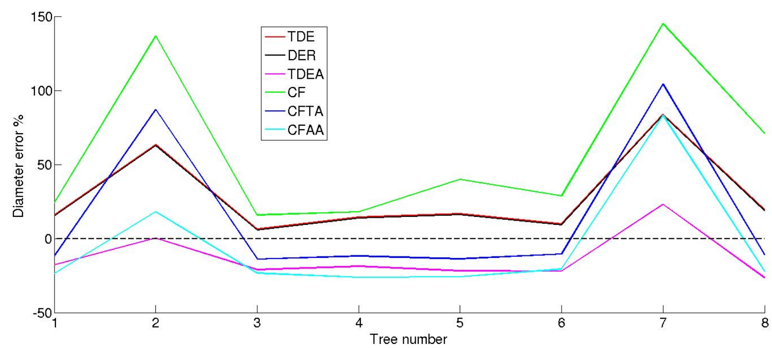
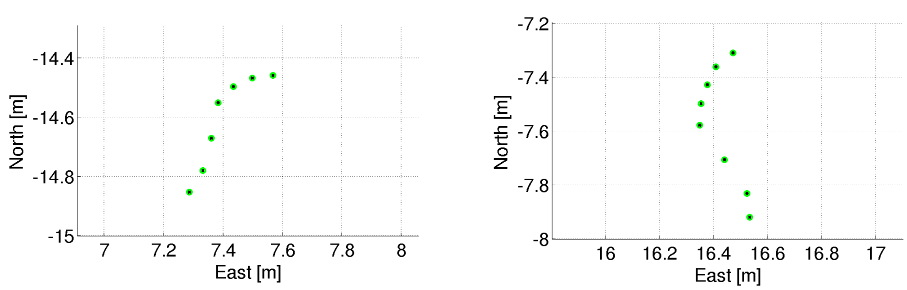


Figure 11: Diameter Error results from Position B1 for all six diameter estimation methods (see Section 4).



(a) Tree No. 2.

(b) Tree No. 7

Figure 12: All points belonging to the tree clusters for trees 2 and 7 in Figure 11. It has a large diameter estimation error due to that a branch or some needles becomes part of the tree cluster.

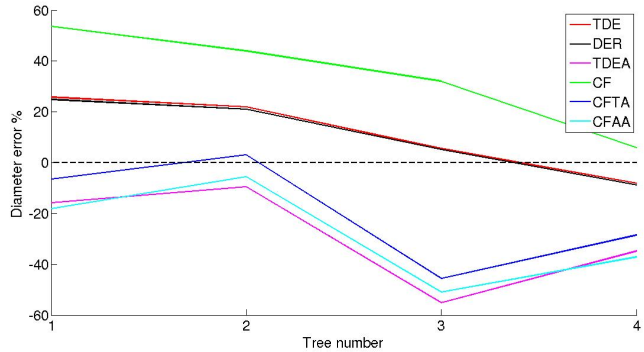


Figure 13: Diameter Error results from Position B2 for all six diameter estimation methods (see Section 4).

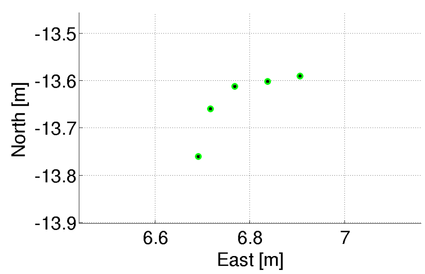


Figure 14: All points belonging to the tree cluster for tree No. 2 in Figure 13. This is the same tree as in Figure 12a, but from a this view the error is lower for all methods.

6 Summary and conclusions

The number of trees identified in this study is not enough for doing much statistics and making general conclusions on the performance of the different algorithms. However some trends were observed. The tree identification algorithm works reasonable well even in a forest with many branches and needles. However, the algorithm is very sensitive to the variables used and hence the outcome could differ. To be able to identify trees in a 2D laser scan even if the tree has branches, needles, and leaves, the variables has to be set differently. It could result in that some of the identified trees being false positives and some false negatives (i.e. some trees are missing and some that are detected are not trees). After testing to remove points with large standard deviation, no real change in the way a tree with branches was found could be seen. The best way to detect trees with branches/leaves was to use the median value of several scans. Using that method did not affect the trees without branches/leaves either.

The result from the different methods for estimating tree diameter vary a lot between three different positions, and no one is the best for all circumstances, although TDEA had the lowest average error for all trees in this test. An important limitation with this test is that the trees where measured at different heights depending on the slope. This means that a part of the diameter error could be from the laser scanner measuring the diameter on a different height than the manual measurement.

TDEA was the best method for position A, where the tree trunks were hidden by branches, and position B1, where the tree trunks were easy to identify. DER was the best method for position B2, where some of the trunks were hidden and some not. The methods based on circle fit (CF, CFTA, CFAA) are not recommended for this kind of work, since they are very sensitive to noise in the positions given by the tree-identification algorithm. The two methods DER and TDE gave rather similar results for all trees.

In general, the errors in this study are larger than reported in previous work [2, 4]. However, more experiments have to be done to get a better statistical basis on the performance of the different algorithms.

7 Acknowledgements

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