Influence of distance to the sensor on stem detection with car-mounted mobile laser scanner

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1. Introduction

The use of Mobile Laser Scanners (MLSs) has been studied in the last decades as an alternative to traditional forest inventory, providing accurate measurements of stem profiles and diameter at breast height (DBH) at tree level in relatively short time (Hyyppä et al., 2020; Liu et al., 2021; Puliti et al., 2020).

There are only a few studies assessing the accuracy to measure forest structure for car- or vehicle-mounted MLS. For instance, Forsman, Holmgren, and Olofsson (2016) proposed an algorithm to detect stem points in an MLS point cloud acquired from a car, yielding an RMSE (Root Mean Squared Error) of 3.7 cm for DBH estimations. Later, Čerňava et al. (2019) tested the performance of a MLS mounted on a tractor used under heavy canopy conditions. They reported an RMSE of 3.06 cm for DBH estimates. Both studies suggest that vehicle-mounted MLSs could be used to conduct forest measurements.

However, car-mounted MLSs might be restricted to the road or skid networks and cannot cover areas inside the forest. Before such MLSs could be used at large scale, it is important to understand the limitations. The main objective of this study is to assess the suitability of a car-mounted MLS to retrieve field reference data from the forest roads. In this study, we refer to distance to the road to express the distance from a specific tree or plot to the sensor´s trajectory. The specific objectives are: (1) to propose an algorithm for ITD (Individual Tree Detection) with MLS data and (2) to assess the influence of the distance to the roadside on ITD.

2. Data and Methods

2.1 Study area and MLS system

The algorithm was validated on the Remningstorp test site, in southern Sweden (lat. 58°N, lon. 13°E). In total, we measured the position and DBH of the trees in 18 circular plots with 10 m radius, organized in 6 groups. In each group, three plot centers were aligned perpendicular to the road. In order to evaluate the effect of the distance from the road on the proposed method´s accuracy, we divided the plots in 3 groups: the first group with the plots closer to the road, from 0 – 20 m, the intermediate group with the plots from 20 – 40 m from the road and last group, from 40 – 60 m. The plots had around 600 trees/ha (80% Norway spruce, 15% pine and 5% broadleaved) and a mean DBH of 27.5 cm.

The MLS data were collected with a car-mounted Riegl VUX-1LR sensor. The car operated with a speed of 5 km/h and the sensor was leaning 30 degrees from the horizontal plane. The sensor emitted near infrared pulses (1550 nm) at a repetition frequency of 820 Hz. The footprint was 5 cm at 100 m from the sensor. This setup yields point clouds with high resolution within scan lines (angular step width of 0.0066 degrees), but large distances between two consecutive scan lines (at least 10 cm). The point density varied according to the distance from the road, as in Figure 1.

2.2 Individual Tree Detection

The proposed ITD algorithm assumes that points belonging to the same stem appear in the point cloud as arcs, and identifies point clusters with a circular shape within scanlines, as in Forsman et al. (2016). Next, we fit circles to the identified arcs in order to eliminate point clusters that do not have a circular shape, using the modified version of Random Sample Consensus (RANSAC) algorithm described by Olofsson et al. (2014). Finally, since the trees were detected independently in each scan line, we needed to vertically aggregate the arcs in order to build individual tree stems. Thus, in the stem segmentation, we associated several arcs to a single stem from the circle center locations obtained in the

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previous step, using an adaptation of the tree stem segmentation proposed by Holmgren et al. (2019). Once the arcs were segmented into stems, we recorded the position of the lowest arc as being the position of the stem.

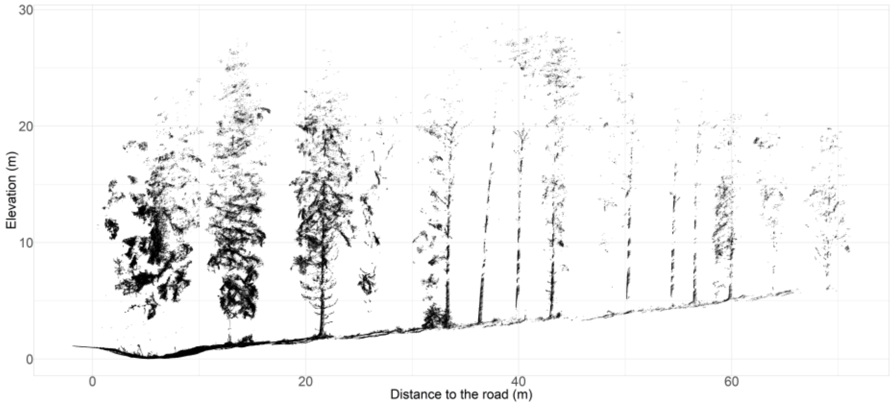

Figure 1: Representation of 3D point cloud, where the point density varies according to the distance from the sensor. The left side is closer to the sensor than the right side and has more points in the canopy and stem than the trees in the right side of the figure.

2.3 Accuracy Assessment

The accuracy of the ITD was assessed zone-wise by matching the MLS-detected trees with the field-recorded tree positions by conducting a search on the surroundings of each MLS-detected tree using a 30 cm radius. If an MLS-detected tree corresponded to a field-recorded one, the tree was considered a true positive. If it did not correspond to any field-recorded tree, it was considered as a false positive. Finally, we considered omission when a field-recorded tree position did not have any correspondence with the MLS-detected individuals. To better understand the performance of the ITD of trees with different size, they were grouped in three DBH classes: DBH < 15 cm, 15 cm <= DBH < 30 cm and DBH >= 30 cm. In each DBH class, we computed the precision (1) and sensitivity (2).

$$Precision = \frac{Number\ of\ true\ positives}{Number\ of\ trees\ found}, \quad (1)$$

$$Sensitivity = \frac{Number\ of\ true\ positives}{Number\ of\ true\ positives + Number\ of\ omissions}. \quad (2)$$

3. Results

Table 1. Individual tree detection´s (ITD) accuracy according to the distance range from the road.

Zone	0 – 15 cm		15 – 30 cm		>= 30 cm	
	Precision	Sensitivity	Precision	Sensitivity	Precision	Sensitivity
First (0 – 20 m)	0.0%	0.0%	92.2%	93.7%	85.0%	85.8%
Intermediate (20 – 40 m)	-	0.0%	98.1%	91.2%	93.3%	100%
Last (40 – 60 m)	-	0.0%	100%	71.9%	100%	87.0%

The ITD performance varied according to the tree´s distance to the road and DBH class. No trees with DBH < 15 cm were detected correctly, regardless of the zone. We noticed the lowest precision in the study (Table 1) in the first zone, from 0 – 20 m, where more than 10% of the trees with DBH >= 30 cm were false positives. The high number of heavy branches and the proximity to the sensor, which makes branches close to the road have a high point density, appears as the main reason for the observed false positives from 0 – 20 m.

The best overall ITD performance was obtained from 20 – 40 m, where the branches were smaller when compared to the ones in first zone, thus, being more easily separated from stems. In the intermediate zone, the point density was not as high as in the first zone, causing less false positives amongst the found trees with DBH >= 15 cm (Table 1).

Finally, in the third zone, from 40 – 60 m, no false positives were noticed (Table 1). However, the sensitivity in the area was the lowest in the study: 71.9% on trees with DBH between 15 – 30 cm. This may be explained by the fact that the point density decreases significantly in areas further from the road, consequently, it is more likely to have fewer returns from the trees in the last zone. However, the sensitivity increased to 87.0% for trees with DBH >= 30 cm, which implies that trees with larger DBHs are found more easily at 40 – 60 m from the road.

4. Discussion

A benchmark of different MLS systems used for forest inventory was reported by Hyyppä et al. (2020), where backpack, handheld and under-canopy MLSs were compared. The authors obtained 100% precision with all the systems. Depending on the forest conditions and the sensor used, the sensitivity ranged from 79.0% to 95.2% with the backpack MLS, 76.7% to 92.9% with a handheld MLS and 81.4% to 92.9% with an under-canopy ULS (Unmanned aerial vehicle Laser Scanner). Our method yielded comparable sensitivities in the first and intermediate zones when considering trees with DBH >= 15 cm. For small trees (DBH < 15 cm), the branches often occluded the stems, especially for Norway spruce trees which was the dominant species. The occlusion combined with the distance from the sensor prevented the detection of stems with DBH < 15 cm.The method we propose can be used at an optimal distance range in which the system is able to detect trees with good accuracy.

MLS systems have been studied for more than one decade as alternatives to manual forest inventories, but still they are not operationally used. The MLS system we tested can be used for automatic large-scale forest assessments, since it can take advantage of the forest roads and skid trails to make measurements on the go during field visits. In terms of autonomy, a vehicle-mounted MLS can operate for a longer time than, e.g., an ULS. Future studies may explore the potential of such system to obtain more measurements of the tree stems, capturing DBH, stem profile and volume. In addition, other methods to improve the ITD´s precision in the first zone may be developed.

5. Conclusions

In this study, we proposed a method capable of identifying tree stems from car-mounted MLS point clouds, collected from the roadside. We could detect trees with a sensitivity and precision comparable with other MLSs that were located in the forest. We observed that the accuracy of ITD decreased as the distance from the trees to the road increased. We recommend establishing an optimal distance range where it is possible to obtain the highest precision and sensitivity.

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