POSSIBILITIES OF CHANGE DETECTION OF TREE AND FOREST ATTRIBUTES BY COMBINING TERRESTRIAL LASER SCANNING BASED 3D POINT CLOUDS WITH UAV DATA

Ville Luoma[1], Tuomas Yrttimaa[2,1], Ville Kankare[2,1], Ninni Saarinen[1,2], Harri Kaartinen[3,4], Antero Kukko[3], Juha Hyyppä[3], Mikko Vastaranta[2] and Markus Holopainen[1]

[1] Department of Forest Sciences, University of Helsinki, FI-00014 Helsinki, Finland

[2]School of Forest Sciences, University of Eastern Finland, P.O. Box-111, FI-80101 Joensuu, Finland

[3] Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute, P.O. Box-15, FI-02431 Masala, Finland

[4] Department of Geography and Geology, University of Turku, FI-20014 Turku, Finland

Correspondence to: Ville Luoma[1] (ville.luoma@helsinki.fi)

Abstract

Exact and up-to-date information about forest resources is needed for decision makers when planning the use of forests. Knowledge about changes in forest environment and tree growth is a key factor for example when predicting the effects of climate change and estimating the amount of biomass and sequestered carbon in forests. New technologies, such as unmanned aerial vehicles (UAVs), allow one to collect detailed information of forests from above with relatively close range. UAVs have already been used e.g. for environmental monitoring, tree attribute detection and forest inventories. However, also accurate and in detail reference measurements are needed for estimating forest resource information, to be able to take advantage of the new methods. Terrestrial laser scanning (TLS) can be used for measuring tree and forest attributes from ground in very high detail. This study shows how follow-up measurements with TLS-based three-dimensional point clouds allow one to investigate the changes both on individual tree and plot level. Based on the results, the possibilities of using TLS data as reference for UAV inventories or together with UAV based measurements are discussed in an attempt to find more accurate and effective solutions for forest change detection.

Keywords: Change detection, UAV, tree growth, terrestrial laser scanning, 3D point clouds

INTRODUCTION

Currently exact, more accurate and up-to-date forest resource information is needed for purposes of sustainable forest management. Knowledge about changes in forest environment and tree growth is required to answer the questions related to climate change, carbon sequestration and forest biomass among others. To be able to provide more exact information on forests for the decision makers, new methods for detecting and measuring changes in forests are needed.

The use of unmanned aerial vehicles (UAVs) for collecting photogrammetric or laser scanning data is one of the new methods for acquiring detailed forest information. Especially on small-scaled areas, data from UAVs has been used for environmental monitoring, assessing biodiversity, detecting individual trees and their attributes as well as for inventorying small forest areas (Puliti et al. 2015; Zhang et al. 2016; Goodbody et al. 2017; Saarinen et al. 2018; Liang et al. 2019; Puliti et al. 2019).

UAVs allow one to view and measure the forest from above on relatively close range, which can be utilized in estimating tree height and the structure of a stand (Nevalainen et al. 2016; Liang et al. 2019). Whereas especially in denser forest conditions, where canopies limit the view on the lower and middle parts of tree stems, estimating the stem diameters accurately has been a challenge (Liang et al. 2019). However, diameter at breast height (dbh), tree height and species are used for estimating e.g. stem volume of a tree and further in creating forest resource information e.g. (Laasasenaho 1982; Kangas & Maltamo 2006). Thus, accurate measurements of these basic tree attributes and tree growth is needed for detecting and monitoring changes in forests. For these purposes, terrestrial laser scanning could be used to collect some parts or all of the data.

Terrestrial laser scanning (TLS) allows one to measure e.g. trees on millimeter scale without damaging the trees. TLS was first used in forest studies in early 2000s (Liang et al. 2016). TLS scans result three-dimensional (3D) data, which has been used for measuring attributes of single trees. Diameter along the stem, tree height, volume of the tree stem, biomass and stem taper can be estimated from the resulting 3D point clouds (Henning & Radtke 2006; Huang et al. 2011; Liang et al. 2013; Saarinen et al. 2017; Kankare et al. 2014; Yu et al. 2013; Kankare et al. 2013).

The aim of this study is to show the capabilities of TLS based change detection in forest conditions and further discuss the potential of using these highly accurate measurements as field reference either for UAV based small-scale forest inventories or forest change detection. To provide a reference for change detection, TLS based 3D point cloud data was used for investigating the tree growth of individual trees on sample plots during a period of six growth seasons.

MATERIAL AND METHODS

The study area is located in Evo, southern Finland (61.19° N, 25.11° E) approximately 100 km north of Helsinki. The area consists of ~2000 ha of forest land with the elevation varying from 125 m to 185 m above the sea level. The dominant tree species in the area are Scots Pine (Pinus sylvestris, L.) and Norway spruce (Picea Abies (L.) H. Karst.) The site type varies from groves to barren heaths.

For this study 6 field sample plots (32 m × 32 m) located on managed stands were mapped and measured. The forest development class on the sample plots varied from advanced thinning to regeneration ready with both Scots Pine and Norway spruce as a dominant tree species on three of the plots, respectively. Sample plot attributes are described in Table 1.

Table 1. Plot level attributes derived from the 3D point cloud data of the six sample plots used in the study. N is the number of stems/ha, D_g is the basal area weighed mean diameter in cm, H_g is the basal area weighed mean height in m and Vol is the stem volume of trees in m^3/ha.

Plot	Main species	N, trees/ha	D_g, cm	H_g, m	Vol, m^3/ha
1	*Pinus sylvestris L.*	381	25,4	20,2	187,9
2	*Picea Abies (L.) H. Karst.*	674	27,7	21,1	369,9
3	*Picea Abies (L.) H. Karst.*	420	38,2	20,4	373,5
4	*Pinus sylvestris L.*	342	32,1	22,3	239,9
5	*Pinus sylvestris L.*	518	19,7	16,2	124,3
6	*Picea Abies (L.) H. Karst.*	566	32,8	20,9	386,8

The field measurements with TLS were carried out in the study area in spring 2014 (T1) and the measurements were repeated in late autumn 2019 (T2). This led to an investigation period of 6 growth seasons. Five TLS-scans were performed on each plot with data collection on the plot following the method presented by Liang et al. (2016). The plot and single tree level attributes were then obtained by using automatic point cloud processing method developed by Yrttimaa et al. (2019). For this study, tree dbh, height, diameter at the height of 6 meters ($d_{6,0}$) and stem volume were automatically determined for all detected trees from the point cloud. On field, the measurement crew determined also manually the number of stems and their location on the plots as well as species, dbh and height of the trees.

On plot level, the change detection was performed by detecting all tree stems with dbh over 5 cm from the point clouds both in T1 and T2. Manual field measurements were used as reference to evaluate the success rate of stem detection.

Trees detected from the point clouds on the six plots were used for investigating the change detection on individual trees. Diameter and volume growth were determined by comparing dbh and volume in T1 to value of respective attribute in T2 to obtain the relative growth. Stem tapering was defined as the difference between dbh and $d_{6,0}$. Change in tapering was calculated by comparing the results from T1 and T2 for each tree.

RESULTS AND DISCUSSION

On the six sample plots 78,8 % of all trees existing at the beginning and end of the investigation period (297 trees out of 377) were detected with the automatic tree detection method both in T1 and T2. The detection accuracy varied between plots from 91,4 % to 68,3 % of trees. On the three plots where Scots pine was the dominant tree species the minimum detection accuracy was 81,4 % and maximum 91,4 %, whereas for plots dominated by Norwegian Spruce minimum and maximum accuracies were 68,3 % and 80,2 %, respectively. Despite that the method was not able to detect all trees on the plots, it could be calculated based on stem volume estimates from both TLS and field measurements, that 92,4 % of the total stem volume on the sample plots was detected with the automatic method. Based on this, the missing trees were mainly small sized.

Out of the 297 detected trees, 251 were used as sample trees in this study. 46 trees had to be discarded due to incomplete attribute estimations. The used method was able to detect the growth of the trees for both dbh and volume (Table 2). Based on the results, the growth was most intensive on plots dominated by Scots Pine (plots 1, 4 and 5). There was no clear change in tapering of the sample trees.

Table 2. The mean dbh in T2 for all six plots as well as the detected change for three investigated attributes. Δdbh and ΔVol indicate the mean relative change in dbh and volume on the sample plots whereas Δtapering indicates the change in stem tapering. For tapering, positive values mean that dbh has increased more than $d_{6,0}$.

Plot	dbh in T2	Δdbh	ΔVol	Δtapering
1	26,4 cm	7,6 % (1,9 cm)	21,5 % (0,098 m^3)	0,2 cm
2	24,6 cm	3,3 % (0,8 cm)	12,5 % (0,063 m^3)	0,1 cm
3	30,1 cm	2,5 % (0,7 cm)	7,4 % (0,050 m^3)	0,8 cm
4	29,7 cm	7,6 % (1,8 cm)	20,8 % (0,133 m^3)	0,5 cm
5	21,0 cm	9,2 % (1,8 cm)	34,2 % (0,082 m^3)	-0,4 cm
6	26,2 cm	5,9 % (1,4 cm)	22,9 % (0,134 m^3)	-0,3 cm

Results show that TLS allows one to measure accurately and follow effectively how individual trees grow and develop. Based on the results, TLS is successful in detecting changes on sample plot level, and it could be used as an accurate method for providing reference data for small-scaled forest change detection and monitoring with UAVs. Both UAVs and TLS have its own limitations in estimating either attributes of lower or upper parts of a tree due to occlusion and the location from where the measurements are performed (Liang et al. 2018; Liang et al. 2019). This is why, for example, point clouds from TLS and UAV measurements could be linked together to improve the accuracy of diameter and height estimates of individual trees by taking advantage of strengths of both methods. This could lead to more accurate estimates of forest growth and thus create more exact forest resource information.

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