ESTIMATING VERTICAL CANOPY COVER USING DENSE POINT CLOUD DATA FROM MATCHING OF AERIAL PHOTOS

Ann-Helen Granholm[1], Nils Lindgren[1], Kenneth Olofsson[1], Anna Allard[1] and Håkan Olsson[1]

1. Swedish University of Agricultural Sciences, Department of Forest Resource Management, Umeå, Sweden; ann-helen.granholm@slu.se, nils.lindgren@slu.se, kenneth.olofsson@slu.se, anna.allard@slu.se, hakan.olsson@slu.se

ABSTRACT

This study aims to explore the use of dense point clouds from matching of aerial photos for estimation of vertical canopy cover (VCC), defined as the proportion of the forest floor covered by the vertical projection of the tree crowns. VCC is commonly estimated using vegetation ratio (VR) derived from airborne laser scanner (ALS) data. A reliable measure of VCC from matching aerial photos would aid in vegetation mapping and reduce the need for repeated ALS data acquisition. The test area is located in southern Sweden and covers a variety of vegetation types. In total 367 sample plots were placed in parts of the study area representing VCC ranging from 0 % up to close to 100 %. ALS data with a density of 20 returns per m^2 was used for calculating the VR as the proportion of first returns above a threshold. Aerial imagery with a ground sample distance of 0.25 m was matched to produce dense point cloud data, which was used to derive digital surface models (DSMs) with grid size from 0.25 m up to 2.0 m. Local maxima (LM) detection was applied to the DSMs with search windows of 0.5 m size up to 2.0 m. The heights of the LM were normalized using a digital elevation model (DEM) derived from ALS data. Regression analysis was applied with the VR as dependent variable and the sum of the height of LM within sample plots as independent variable. Results from linear regression using heights of LM detected in a DSM of 0.25 m resolution with a 0.5 m search window gave an root mean square error (RMSE) of 5.5 % and relative RMSE (rRMSE) of 9.3 % in forest on rocky outcrops and boulders, while wooded pasture gave RMSE = 6.3 % and rRMSE = 19 %.

INTRODUCTION

Vertical canopy cover is the area of the ground covered by a vertical projection of the canopy, as defined by (1). An internationally accepted definition of forest is based on canopy cover and tree height (2), which is why a reliable measure of VCC is of importance for the separation of forest from non-forest. Accurate and non-biased field measurement of VCC is time-consuming (3) while studies have showed that VCC can be estimated using airborne laser scanner (ALS) data (4, 5). However, ALS is an expensive alternative for repeated measurements.

Matching of digital aerial photos has proved to be useful for production of digital surface models (DSM) and for estimation of tree heights and other forest variables in case there is an accurate digital elevation model (DEM) available (6, 7, 8, 9). The National Land Survey of Sweden collects national coverage of aerial imagery every third year on average. Combined with the national DEM, this imagery could be used for production of dense point clouds on a national scale and thereby provide ample data for vegetation mapping and change detection. The National Inventory of the Landscape in Sweden (NILS) programme, which aims is to monitor the condition and changes in the Swedish landscape, would for instance benefit from affordable metrics useful for estimating VCC (10). Currently such estimations are done manually by aerial photo interpretation (11), which is time-consuming and introduces potential errors caused by differences between interpreters. A common method for estimating VCC with ALS is by using the vegetation ratio (VR), which is calculated as the proportion of first return echoes above a specified height threshold. Using ALS data with as low scan angle as possible helps produce estimates of VCC with a low bias (5).

Simply replacing first return echoes from ALS data with dense point cloud data from matching results in incorrect estimations of VCC, due to the overrepresentation of canopy returns which is caused by the occlusion of the ground in aerial photos covering forested areas. Therefore, we chose instead to use the sum of tree height as an estimation of VCC, inspired by the correlation between tree crown diameter and tree height (12). In this initial test, we tried using single tree detection, by which it is possible to gain both tree height and position. There are a number of techniques available for single tree detection in aerial photos (13) and ALS data (14). Local maxima filtering (15) was chosen for this study, and applied to DSMs based on dense point cloud data from matching of aerial photos. The detected local maxima were used to produce metrics which, in turn, were compared to VR based on ALS data.

METHODS

Test area

The test area is approximately 5 by 8 km in size, located in the south of Sweden, Lat. 58º 30′ N, Long. 13º 40′ E. Several vegetation types are found within the test area, which was divided into four strata; 1) managed forest of Scots Pine (*Pinus Sylvestris*), Norway Spruce (*Picea Abies*), and Birch (*Betula spp.*) on fertile sites, 2) open and wooded wetland, dominated by Scots Pine, 3) rocky outcrops and boulder areas with partial tree cover, dominated by Scots Pine, and 4) open and wooded pasture with a mix of hardwood broad-leaved trees, other deciduous tree species, and occasionally Norway Spruce trees.

Remote sensing data

ALS data with a density of 20 returns per m^2 was acquired in September 2014 by a private contractor using a Riegl LMS Q680i mounted on a helicopter flying at an altitude of 440 m. Aerial imagery covering the test area was acquired in July 2014 by the National Land Survey using a Vexcel UltraCam X camera at an altitude of 2900 m above ground, producing photos with a ground sample distance of 0.25 m and stereo overlap of 60 % in the flight direction. The aerial photos were matched using the software Match-T by Trimble.

Reference data

367 circular sample plots, with a radius of 20 m, were distributed subjectively within the test area, to collect samples representing VCC ranging from 0 % up to close to 100 % in each stratum. The sample plots were placed within a range of 10º from nadir in relation to the flight path. Aerial photo interpretation was used for collecting information regarding land cover and dominating tree species (Table 2).

ALS VR was used as reference data for VCC. The ALS point cloud was classified into other vegetation and ground hits using the algorithm by (16, 17). LAStools (18) was then used to process the point cloud; flight line overlap was removed and the height of the laser returns was normalized to above ground. All returns but first and single returns were dropped from the ALS point cloud, which was then thinned down to one point per 0.5 * 0.5 m using grid cells, where one randomly selected point for each cell was kept. This was done in order to avoid effects of uneven point densities. The thinned point cloud was used to calculate ALS VRs for each plot, defined as the number of returns above a threshold divided by the total number of returns (19). The thresholds; 1, 2, and 3, were used to produce three separate VRs; VR1, VR2, and VR3.

Local maxima detection in point cloud data

Local maximas (LM) in the point cloud data were detected in a two stage process: 1) the top surface layer was projected to a canopy raster, 2) every grid cell of the canopy raster was compared to its neighborhood. If the grid cell within a search window was the highest in its neighborhood it was chosen as a LM. Canopy rasters with different resolutions and search windows with different sizes were compared to find the optimal parameter settings (Table 1).

To produce a canopy raster, all height values from the point cloud data were projected to a raster of a pre-chosen resolution. The highest value within each grid cell was chosen to be the final canopy height at that position. The search windows, used to find the LM of the canopy raster, had a circular geometry. Every neighbor pixel with the center within the search radius was used for comparison. If the radius of the search window was smaller than or equal to the raster cell size, the search window was set to a 3x3 square window. If the center pixel of the search window had the highest value it was considered to be a LM of the canopy. The height and position of the LM was saved in a list for further processing.

Table 1. Combinations of raster resolution and search windows radius (m)

Raster cell size	Search window radius
0.25	0.50; 1.00; 1.50; 2.00
0.50	0.50; 1.00; 1.50; 2.00
0.75	0.75
1.00	1.00; 2.00
2.00	2.00

The height of the detected LM were normalized using a digital elevation model (DEM) derived from ALS data. The normalized height of the detected LM above 3 m within sample plots was summarized per sample plot ($\sum h$), as well as the sum of squared normalized height of LM within sample plots ($\sum h^2$), for each combination of raster resolution and search window radius.

Simple linear regression analysis was applied using the VR derived from ALS as dependent variable and $\sum h$, and $\sum h^2$, respectively, as independent variable, in separate regressions. The three different VRs were tested one by one in separate regressions against $\sum h$, and $\sum h^2$, respectively. Scatter plots suggested a transformation by taking the square root of the independent variables ($\sqrt{\sum h}$, and $\sqrt{\sum h^2}$). The accuracy of the results was examined by calculating root mean square error (RMSE) and relative RMSE (rRMSE) between the VRs and $\sum h$, $\sum h^2$, $\sqrt{\sum h}$, and $\sqrt{\sum h^2}$, respectively. The analysis was performed per stratum.

Table 2. Characteristics of sample plots per strata. Height information derived from ALS data.

Strata	Number of sample plots	Height percentile 90~~-~~, range and mean (m)	Number of detected LM within plots (grid cell 0.25 m, search window 0.50 m), range and mean	Dominating tree species
Managed forest	174	1.4 – 30.6 (15.6)	0 – 698 (436)	Norway Spruce, Scots pine, Birch
Wetland	21	1.2 – 16.7 (7.8)	0 – 611 (179)	Scots Pine
Rocky outcrop or boulder	28	10.0 – 21.0 (15.5)	58 – 623 (411)	Scots Pine
Pasture	87	0.0 – 24.8 (16.0)	0 – 616 (210)	Hardwood broadleaved trees, also Birch

RESULTS

Our results indicate that the square root of sum of heights of detected LM per plot ($\sqrt{\sum h}$) corresponds well with VR from ALS in some of the sparsely covered strata, such as “Rocky” and “Pasture”, for which we received the lowest RMSE and rRMSE (Figure 1). These results are promising considering the needs of a potential user, the NILS programme, who would benefit from information on VCC in the range of 0 – 40 % to efficiently separate open areas from forest (10).

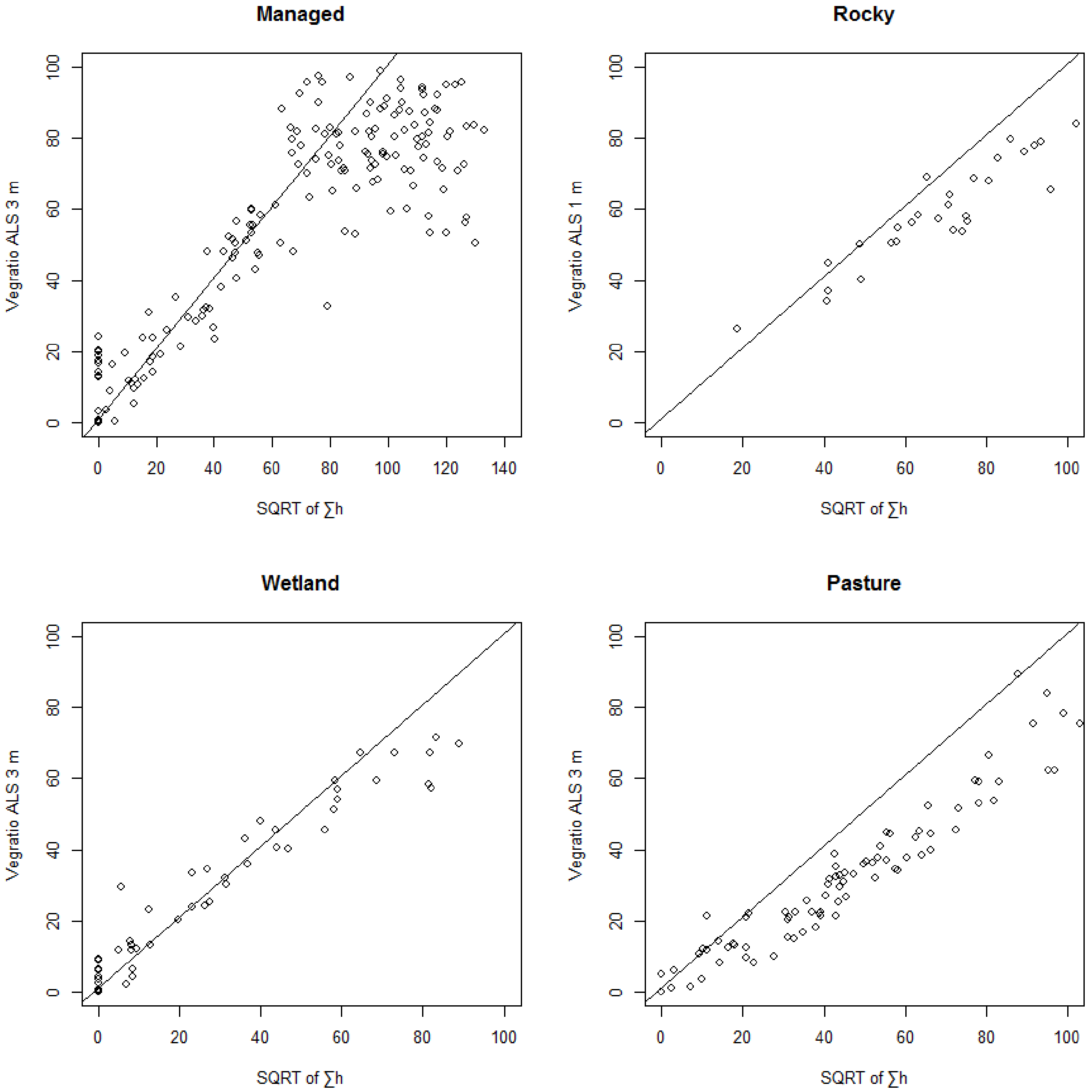

Figure 1: Comparison of the square root of sum of heights of local maxima (√∑h), detected in raster with 0.25 m grid cells and 0.5 m search window, with VR from ALS with thresholds of 1, or 3 m above ground. 1:1-line was added as a comparison. "Managed" with RMSE = 57 %, rRMSE = 101 %, range = 0 – 99 %, mean = 56 %. "Rocky" with an RMSE = 5.5 % and rRMSE = 9.3 %, range = 26 – 84 %, mean = 58 %. "Wetland" with RMSE = 6.0 %, rRMSE = 21.1 %, range = 0 – 72 %, mean = 28 %. "Pasture" with RMSE = 6.3 %, rRMSE = 19 %, range = 0 – 92 %, mean = 33 %.

The results also show that the sum of heights of detected LM is not applicable at high values of VR, which was the case in the stratum "Managed". This is likely caused by the lack of gaps and small openings in densely forested areas in the DSM based on maxfiltering. Another problem was observed in sample plots with a few tall Scots Pine trees left as seed trees in clear cuts (included in the strata "Managed"). These solitary trees were not visible in the point cloud data from matching, and were therefore not detected as LM, though they were visible to the eye in the aerial photos and in the ALS point cloud. This error is most likely caused by shortcomings of the matching algorithm, which is why other matching algorithms should be tested and evaluated. It should be noted that in "Wetland", where the same tree species was dominant, the matching algorithm was capable of producing points in the sparse canopy, even though the trees were generally of a lower height. Using a combination of small cell size and small search window radius, gave the highest density of LM per sample plot and the lowest rRMSE, but also plenty of "false trees" since the number of LM exceeded the true number of trees by far. Considering the large amount of false trees, this was not a successful attempt at single tree detection. Although the difference in rRMSE between combinations of grid size and search window radius was barely significant, we consider investigating the potential of binary canopy maps, such as in (5), since the highest densities of LM resembled first return echoes of thinned ALS data rather than single trees.

CONCLUSIONS

Our results show that there is potential in using dense point cloud data to produce metrics which correspond with low values of VR based on ALS. Further studies are needed to develop a method which is suitable in a variety of forests and wooded areas.

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