ASSESSING PROTECTION FOREST STRUCTURE WITH AIRBORNE LASER SCANNING IN STEEP MOUNTAINOUS TERRAIN

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ABSTRACT

Protection forest management requires reliable data on the structural characteristics of forest stands with high spatial resolution, which could be delivered by airborne laser scanning. We subtracted a digital surface model (DSM), derived from the last LiDAR pulses, from a digital terrain model (DTM), derived from the first LiDAR pulses, to obtain a "normalized crown model" (nCM). The resolution of the rasters was 1 m × 1 m. With two methods that are based on local maxima identifiers individual tree tops were detected with a mean error of 33% when comparing the number of detected trees with the measured number of trees present in the validation plot. When only taking into account the dominant and co-dominant trees, this error decreased to approx. 10%. Position errors of the trees that were automatically identified in the nCM were between 0.5 and 3.5 m, when comparing to on-site GPS measured positions. Field investigations on the causes of errors in the number of detected trees showed that they are mainly caused by trees growing in collectives. Errors in tree positions are related to tilted trees and 'missed' tree tops during scanning, as well as the cumulative errors between GPS measured positions of the base of trees and the LiDAR position. In conclusion, we are of the opinion that airborne laser scanning provides excellent data for protection forest management. It provides reliable information on the positions of individual, dominating and co-dominating trees and on the position of collectives and the tree heights. In addition, it provides excellent input data for 3D natural hazard simulation models, even in steep terrain.

Keywords: *Protection forest, local maxima, tree top identification, LiDAR*

1 INTRODUCTION

Many forests in the Alps cover steep to very steep slopes (gradients of 35 - 70 degrees) and have an important protective function against natural hazards, such as rockfall and snow avalanches. In order to sustain the protective effect of these forests, they have to be managed. This requires reliable forest data with high spatial resolution, which could be delivered by LiDAR (Lim et al. 2003). The aim was to retrieve information on the structural characteristics of a protection forest stand, especially, the tree positions and the tree height using airborne LiDAR (Light Detection And Ranging, also called laser scanning), which has been shown to be feasible in less steep terrain by Popescu et al. (2002) and Zimble et al. (2002). We specifically investigated whether reliable information of trees growing on steep slopes can easily be obtained. As most foresters use raster data in standard Geographical Information Systems (GIS) instead of 3D point clouds, we tested two methods that are based on the identification of local maxima on raster data in this study.

2 METHODS

2.1 LiDAR data

The test site for this study is the 'Schmalzberg' forest, located in the Montafon region in the western part of Austria. The forest, which is dominated by Picea abies, covers a steep slope (up to 40º) and protects residential area downslope against rockfall and snow avalanches. This site has been scanned on the 10th of December 2002. The used laser scanner was a first/last pulse Airborne Laser

Terrain Mapper (ALTM 1225) made by Optech Inc. (Canada). The pulse rate of the ALTM is 25 kHz, which resulted in a point density of 0.9 points m-2 at an average fly altitude of 1000 m above ground level. With a laser beam divergence of 0.3 mrad, the average footprint on the ground was about 0.30 m. The average ground swath width was about 725 m, the maximum scanning angle 20º (Wever 2002).

The data obtained by the ALTM have been filtered and interpolated by the TU Vienna to create a digital terrain model (DTM) and a digital surface model (DSM), both with a resolution of 1 m × 1 m and a size of 500 × 500 cells. Since most users of LiDAR data would obtain similar data, we used these two rasters as the basis data for our study. By subtracting the DTM from the DSM we obtained a "normalized crown model" (nCM), which gives an estimate of the height of vegetation or similar obstacles.

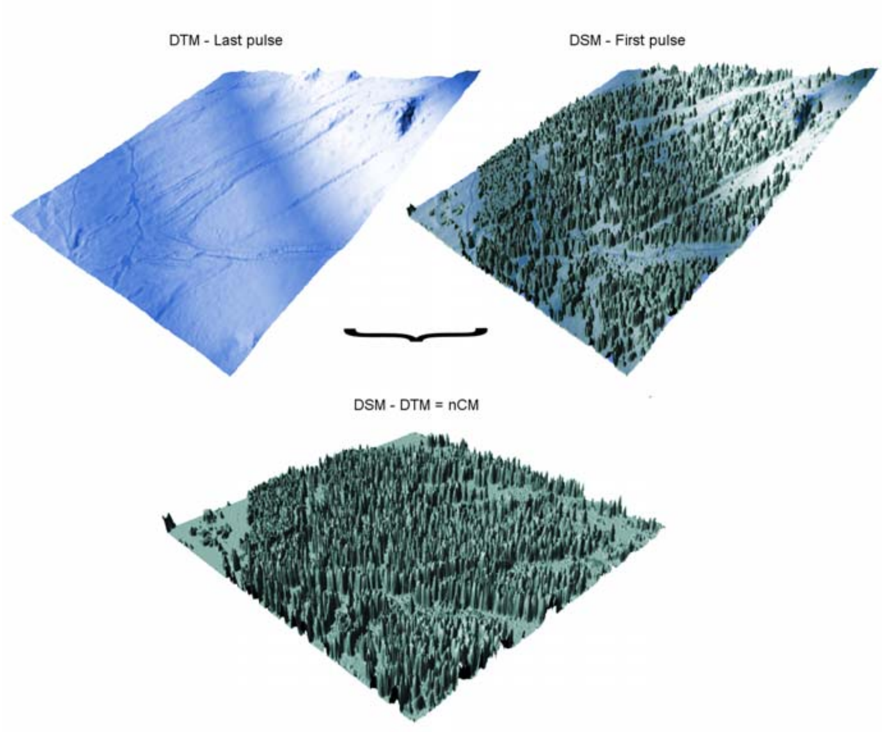

Figure 1: The 500 × 500 rasters of the study area and the creation of the normalised crown model (nCM).

2.2 Validation data

A detailed inventory within a sample plot with a 20 m radius has been carried out. Here, we measured the diameter at breast height (DBH), the tree height and the exact position of 30 trees with DBH>10 cm using a compass and an ultrasonic vertex from the sample plot centre. The position of the centre has been measured with a differential GPS. Position errors were estimated to be 0.43 m and tree height measurement errors between 0.5 and 1 m, due to the steep terrain (Maier 2005).

2.3 Tree heights and positions

To extract tree heights and positions from the nCM, we tested two methods that are based on the identification of local maxima, where those maxima are regarded as tree tops. The first method uses a variable window size (VWS) that is determined by the tree height, similar to Popescu et al. (2002). The VWS method is supported by an empirical relationship between the crown size and the tree height that is similar to Hasenauer (1997), but which is based on 500 measured tree crowns and heights in a similar forest in the area (Dünser 2002). For trees with a height up to 20 m a 1-cell window radius was used, for 20 – 30 m a 2-cell radius and for larger trees a 3-cell radius. The VWS method can be performed in a standard GIS. The second method, called Tree-top Window Analysis (TWA), is programmed in Matlab and evaluates for each cell in the nCM, which has a value larger than the defined *minimum tree height, whether it is a local maximum. Each cell is evaluated with a 3×3 window. If the evaluated cell is a local maximum, the window diameter is enlarged with two cells. Then, the evaluation is repeated. As such the method assesses the dominance of the cell over all surrounding cells. The TWA method also provides information on 'sub-maxima'. This is a cell that adjoins the local maximum with a height gradient less then 45º between the two. Condition for a sub-maximum is that all cells in the window have a lower value except for the local maximum. Such a sub-maximum could represent a tree that grows in or near a tree collective.*

3 RESULTS

Figure 2 shows the sample plot with the 30 measured and all the detected tree tops. The bigger the blue in this figure dots, the larger the probability of detecting a real treetop, as calculated by the TWA method. The plot also shows the positions errors between the measured tree positions (at breast height) and the detected tree tops. Nevertheless, the heights of the detected tree tops can be used to relate them to the measured ones. The result of this comparison is given in Table 1. This shows that the TWA method detected 25 trees in the sample plot of which 21 were correct. The VWS method detected 20 trees of which 19 were correct. Position errors between the measured tree bases and the detected tree tops ranged from 0.4 – 3.5 m. The error of identifying tree tops is 33% for the TWA and 36.7% for the VWS method, when comparing with all the trees present in our validation plots. When only taking into account the dominant and co-dominant trees (non hidden trees in collectives), the mean error decreases to approx. 10%.

Table 1: Results of the comparison between measured trees and detected trees using the TWA method, the VWS method and two local maxima filters, one with a 2-cell radius and one with a 3-cell radius.

			Detected Height (m)				
Tree nr	Species	Measured height (m)	TWA	2-cell window radius (fixed)	3-cell window radius (fixed)	VWS	dH
1	Picea abies	29,0					-
2	Picea abies	35,0	35,6	35,6	35,6	35,6	-0,6
3	Picea abies	35,5	40,3	40,3	40,3	40,3	-4,8
4	Picea abies	21,0	18,7	18,7	18,7	18,7	2,3
5	Picea abies	32,0	33,2	33,2	33,2	33,2	-1,2
6	Picea abies	37,0	40,1	40,1	40,1	40,1	-3,1
7	Picea abies	15,0					-
8	Picea abies	22,5					-
9	Picea abies	36,5	31,3				5,2
10	Picea abies	32,5	33,2				-0,7
11	Picea abies	34,0	36,0	36,0	36,0	36,0	-2,0
12	Snag	22,5	35,0	35,0		35,0	-12,5
13	Snag	34,0	35,6	35,6	35,6	35,6	-1,6
14	Picea abies	30,5	34,7	34,7	34,7	34,7	-4,2
15	Picea abies	34,0	33,1	33,1	33,1	33,1	0,9
16	Snag	34,0	30,4	30,0	30,0	30,0	3,6
17	Picea abies	39,0	39,6	39,6	39,6	39,6	-0,6
18	Picea abies	32,5	34,5	34,5			-2,0
19	Picea abies	25,0					-
20	Picea abies	34,0	35,0	35,0	35,0	35,0	-1,0
21	Snag	34,0	35,9	35,8	35,8	35,8	-1,9
22	Picea abies	26,0					-
23	Picea abies	31,0	32,4	32,4	32,4	32,4	-1,4
24	Picea abies	39,5	35,7	35,7	35,7	35,7	3,8
25	Picea abies	26,0	25,0	25,0	25,0	25,0	1,0
26	Picea abies	15,0					-
27	Picea abies	34,0	33,2	33,2	33,2	33,2	0,8
28	Picea abies	8,0					-
29	Picea abies	13,5					-
30	Picea abies	27,0					-
Correctly detected			21/30	19/30	17/30	18/30	
Total trees detected (wrong ones)			25(4)	20(1)	18(1)	20(2)	

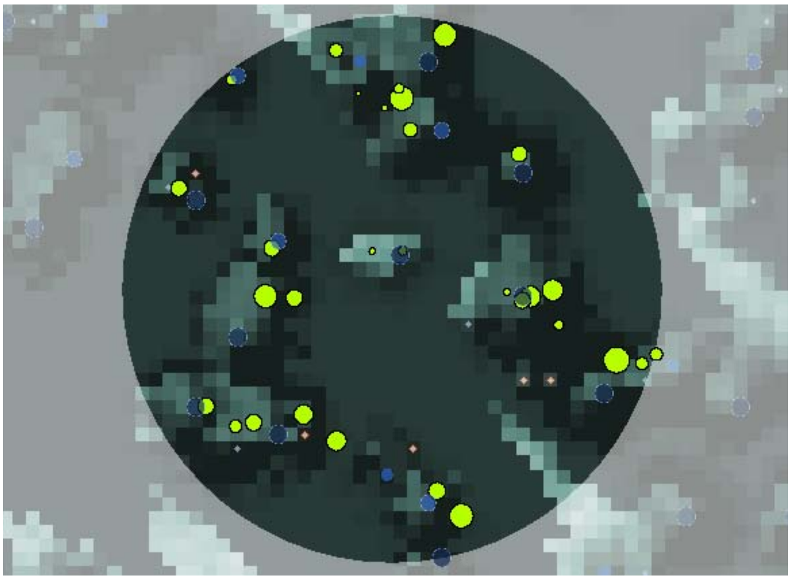

Figure 2: The sample plot with the measured trees depicted as yellow circles. The trees detected by the TWA and the VWS method are depicted as blue and small grey dots. The small white dots with the red outline were only detected by the TWA method.

4 DISCUSSION

The photos in Figure 3 illustrate examples of sources of error in LiDAR based tree detection. The detection of tree collectives (in German Rotten, see left photo) posed problems for all the methods used in this study. In collectives, trees are growing so close to each other that individual tree crowns cannot be detected, which results in one large collective tree crown after crown delineation. All the trees that were not detected by the LiDAR are growing in or near such collectives. The middle photo shows a dead standing tree (snag). Unexpectedly, all snags were detected in our sample plot, but their crowns were absent as almost no light beam is reflected by their branches. The right photo shows a tilted tree. Errors in tree positions are probably related to such tilted trees and 'missed' tree tops during scanning, as well as the cumulative errors between GPS measured positions of the base of trees and the error in the LiDAR detected tree top.

Figure 3: Examples of sources of errors in a LiDAR derived nCM (see text for explanation).

5 CONCLUSIONS

Methods based on the identification of local maxima work well for identifying the position of individual trees, as well as for determining their tree height, also in steep terrain. However, collectives consisting of multiple trees growing close to each other are detected as single tree crowns. Therefore the number of trees as detected by LiDAR in our test site is systematically underestimated. The size of the collective tree crown could probably be used as an indicator for the number of tree stems that constitute the collective in reality. Our final aim is to describe the structural characteristics of protection forest stands using LiDAR for (a) management planning, but also for (b) integrating stand characteristics (tree positions, tree heights and their DBH) in snow avalanche and rockfall simulation models (e.g., Dorren et al. 2004). Regarding tree collectives, which occur frequently in protection forests in the Alps, the problems encountered when using LiDAR can probably be solved satisfactorily by using spatial statistics and probabilistic approaches. Future research would have to focus on developing a generic and persistent method for estimating the number of trees that constitute a collective. Other solutions might be to use the raw 3D LiDAR data in combination with methods described by Zimble et al. (2003) and Maltamo et al. (2005) or the use of the full waveform LiDAR.

The DTM of steep mountainous terrain provided by LiDAR and the positions and heights of individual trees derived from the DSM have an enormous added value for natural hazard simulation models in comparison with traditional DEMs obtained from photogrammetry and tree positions derived from orthophotos. In the future we will focus on adding criteria in the TWA method to improve the estimation of the probability that a detected local maximum or sub-maximum is a real tree top. Then, the improved method should be tested and validated on a larger scale and in other types of forest than pure Picea abies stands, such as mixed montane forests and pole forests.

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