Reconstruction of Urban Vegetation Based on Laser Scanner Data at Leaf-Off Aerial Flight Times – First Results

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Abstract **– Caused by the importance of urban vegetation volume as an indicator for ecologically orientated city planning and since there are several cities which already use laser scanner data at leaf-off aerial flight times for creating 3-D city models the idea merges of using this data for that purpose. This paper deals with the question whether laser scanner data that has not been taken during the vegetation period allows a determination of vegetation volume with sufficient accuracy.**
The work sets up on previous results where laser scanner data has been compared to photogrammetrically determined vegetation height measurements. Starting from the existence of different response characteristics within various vegetation types the ratio of point density of classified non-ground points is detailed analysed, and might be used as a parameter for a point density controlled reconstruction of the laser response within the vegetation stock. Attempts of reconstruction are demonstrated.

Keywords: Laser scanning, LIDAR, Urban studies, Vegetation volume, Reconstruction, Point density, DSM, Three dimensional.

1. INTRODUCTION

Since urban vegetation is an essential need for the urban population there is a growing demand on the part of the environmental protection agencies for indicators for a quantitative description of the vegetation and its development. The indicators related to the vegetation like the biotope area index, and soil function index, or the vegetation volume index with its special ecological statement are counterparts to the indicators for the structural use of land like the site occupancy index and the floor-space index (e. g. Heber, 1993; Kenneweg, 2002). While the biotope area index and the soil function index can be recorded two-dimensionally; for the calculation of the vegetation volume a three-dimensional survey is essential necessary.

But there is a lack of all-covering and up-to-date information about the vegetation volume. Even, in the meantime, if Green Departments of cities partly have tree cadastre it includes just a small part of the necessary information about vegetation. Usually the tree cadastre includes only tree stocks in property of the city but the extensive tree stock of private gardens and properties as well as parks which do not belong to the city are not recorded. In addition the vegetation doesn't only change seasonal but also because of the highly dynamic urban development (succession of fallow ground, the changing of green areas, cutting and felling of trees). At present most cities are lacking detailed information about their urban vegetation.

That is the basis for the development of efficient methods for all-covering surveys of urban vegetation including the determination of the vegetation volume. In only few cases where it had been recorded, its determination was based on the mapping of vegetation areas including the capturing of a medium vegetation height on these areas (e.g. Arlt, 2002). This kind of determination is very complicated and costly, rather inaccurate and gives an acceptable value only for larger area units.

Now, the height measurements of the vegetation stock on the basis of laser scanner data have been tested many times and have proved to be worthwhile in forestry praxis like for example the measurement of forest stocks; e. g. tree height, canopy, crown surface shell and crown radius (e. g. Holmgren, 2003; Hese 2002; Natscan Proceedings). For forestry vegetation determination one uses data recordings from vegetation periods. Whereas in urban areas there are only laser scanner data from leaf-off aerial flight times since the emphasis is hereby on the creation of 3-D city models and Digital Elevation Models (e.g. for flood modelling).

Laser scan aerial flights of urban areas during the vegetation period for determining the vegetation volume is desirable but considering the limited financial means of local authority districts not affordable. This leads to the question if and how existing laser scanner data of leaf-off aerial flight times can be used for determining the vegetation volume. Even if it is less exact than a determination of vegetation volume during summer season the results expected can be much more reliable than a conventional area-related estimation of the height of the vegetation volume.

2. LASER SCANNER RESPONSE IN VEGETATION STOCKS OF LEAF-OFF SEASON RECORDS

The work build up on classified point clouds (ground and non-ground points) processed from the last laser return and captured with ALTM 1225 (1.1 points/m²) by the Company TopScan. This data set is typical for DTM production for several cities. In order to generate a vegetation-nDOM processing of the first pulse leads to a considerable advance, but has been recorded only in the past few years and is processed on demand only.

A detailed determination of laser scanner response characteristics in vegetation stocks at leaf-off aerial flight times is demonstrated in Meinel/Hecht (2004). In this work errors of laser signal regarding height, density and classification in vegetation stocks have been compared to photogrammatrically determined vegetation height measuring (reference-nDSM) and they are now briefly summarized as the starting point for the following chapters as well as for future work on this topic. The main vegetation types: shrub, deciduous tree and conifer have been surveyed on

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representative test areas regarding their response characteristics (Table 1).

The vegetation volume of conifer stocks and shrubs can be exactly determined by airborne laser scanner even during the leaf-off season because of the dense conifer's and tree branches whereas the data of leafless deciduous trees show a big measurement error.

Vegetation Type	Shrub (2.5 - 8 m)	Conifer (3 - 30 m)	Deciduous tree (3 - 30 m)
Number of test areas	29	25	36
Total test area [m²]	1 498	1 991	31 783
Total number of laser points	1 708	2 330	33 590
Part non-ground points [%]	52.0 (23.6)	89.4 (7.5)	5.5 (4.3)
Reference height [m]	2.5 (1.1)	12.3 (3.7)	14.1 (4.0)
Laser height [m]	2.3 (0.9)	12.3 (3.8)	7.9 (2.4)
Reference Green Volume [m³/m²]	1.6 (2.0)	10.1 (4.1)	10.9 (5.0)
Laser Green Volume [m³/m²]	1.5 (2.6)	9.9 (4.2)	0.8 (0.6)
Underestimation of volume [%]	4.1	6.5	91.7

Table 1. Reference and laser scanner differentiated according to vegetation types in comparison of part of non-ground points, medium height and volume (standard deviation in brackets).

Despite a laser point density of 1.1 points/m² only 5.5 % of the laser impulses are reflected by the tree branches and therefore recognized as surface points. The remaining laser impulses penetrate the tree and are reflected by the ground (classification as ground points). Single trees are often represented by one non-ground point. In addition with the measurement data classified as non-ground points, the vegetation height has been underestimated by approximately 44 % on average. Figure 1 shows the measurement of a big oak tree. The main problem is therefore a necessary correction of the laser model in deciduous tree stocks.

a)   b)   c)

=> Underestimation by 97.6 % with laser-nDSM

d)   e)

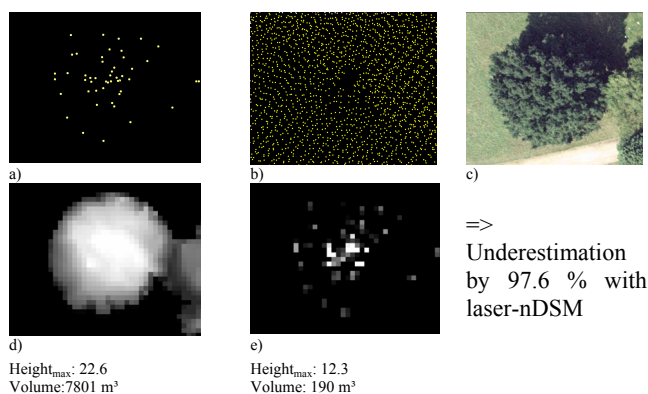Height_max: 22.6
Volume: 7801 m³

Height_max: 12.3
Volume: 190 m³

Figure 1. Situation at a big deciduous tree (oak tree): a) non-ground points, b) ground points, c) color aerial image, d) reference-nDSM, e) laser-nDSM.

3. SEPARATION OF VEGETATION FROM ANTROPOGENIC AREAS

For determining the vegetation volume it is absolutely necessary to separate vegetation from antropogenic non-ground points like buildings as well as streetlights and vehicles. The separation can be carried out via the NDVI in CIR aerial images (date of survey during the vegetation period; scale approx. 1: 5 000). In this process the NDVI is binarized from a visually determined threshold value and results in the required vegetation mask.

If there aren't any CIR aerial images available then it is possible to at least separate built-up areas from vacant areas with limitation in accuracy only on basis of laser scanner data during a non-vegetation period. This method has a disadvantage since grass areas, which have a volume of 0.1 m/m² as well according to Großmann (1984), can not be separated from sealed areas at almost ground level. In literature there are various methods for extracting the building outline; for instance the application of height threshold values with a corresponding extraction of roofs (Rottensteiner et. al., 2002), maximum likelihood classification of multi-band images containing texture measurements (Maas, 1999) a.s.o.

Mainly in cities there are many allotments (garden houses and flat garages). Therefore with the known methods there are still errors in determining of small and flat buildings. In our work selected methods of segmentation of building ground plan on the basis of image processing have been tested and compared to each other. Within the framework of this paper we can't go further into this topic.

4. BASIS OF RECONSTRUCTING THE VEGETATION SIGNAL

As shown in Table 1 the non-ground point density correlates with the vegetation density. Concerning the shrubs the ratio of the number of non-ground-points to the total number of points is approx. 1:2 (52.0 %) and concerning the conifer stocks 9:10 (89.4 %); whereas deciduous tree stocks are only shown in a ratio of 1:20 (5.5 %). Because of this very strong differentiation the local determination of the proportion of non-ground point density to the total point density allows a reliable hypothesis about the type of vegetation. With that a basis for a model-controlled reconstruction of the laser signal in vegetation stocks is fulfilled. To a large extent with conifer stocks and shrubs you don't need a signal reconstruction since their volume can be determined by just the calculation of the nDSM - the difference between DSM and DTM. Whereas deciduous tree stocks have to be reconstructed by few far apart located non-ground points while ignoring close ground points in this area and are then corrected by an afterwards multiplication with a height correction factor regarding the height underestimation (see chapter 5).

For calculating the local density it's absolutely necessary to use the relative non-ground point density since the absolute non-ground point density is almost twice as high because of double covering in overlapping swaths as in single covered areas. There have been determined a minimum point density of 0.0 and a maximum point density of 3.8 measurement points/m² over the total measurement area of the city Dresden. In Figure 2a one can clearly recognize the overlapping swaths shown as light spots with approx. 2 points per m².
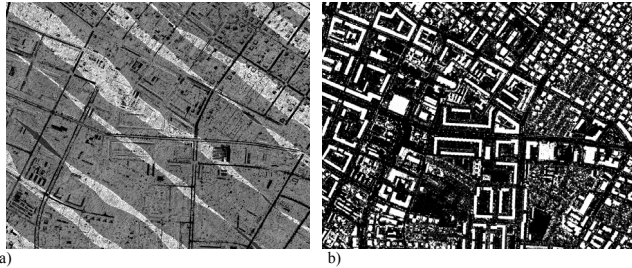
Figure 2. a) Point density of all laser points, b) relative non-ground point density (2 m search radius).

The dark areas represent a small reflection coefficient which is typical for darker areas, asphalt or wet surfaces. The relative non-ground point density results in a percentage of non-ground points to the total number of points determined in a circular search radius around each cell. Buildings consist only of non-ground points and are shown in Figure 2b as white areas.

Over the whole survey area (urban area Dresden: 328 km²) the density images of 1 m cell size have been calculated on the basis of different search radii and separately analysed for the representative testing areas of the three main vegetation types.

	Shrub (2.5-8 m)	Conifer (3-30 m)	Deciduous tree (3-30 m)	
1m Radius	41.3 (23.3)	74.3 (24.9)	8.8 (11.6)	
2m Radius	39.1 (20.5)	73.0 (23.3)	9.2 (11.5)	
4m Radius	33.2 (18.5)	65,8 (20.6)	9.1 (11.3)	
6m Radius	29.9 (18.5)	58.1 (18.5)	9.0 (11.2)	
8m Radius	26.9 (16.0)	52,2 (16.5)	8.7 (10.9)	

Table 2. Relative non-ground point density [%] for varying search radii in dependency of vegetation type and point density image with the oak tree as an example (standard deviation in brackets)

Table 2 and the corresponding diagram (Figure 3) show that the different vegetation types are separable without any problems because of the relative non-ground point density.
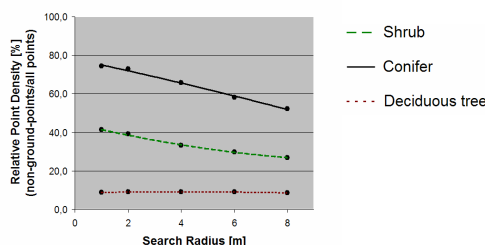

Figure. 3. Relative point density (non-ground-points/all points) for different vegetation types and varying search radius
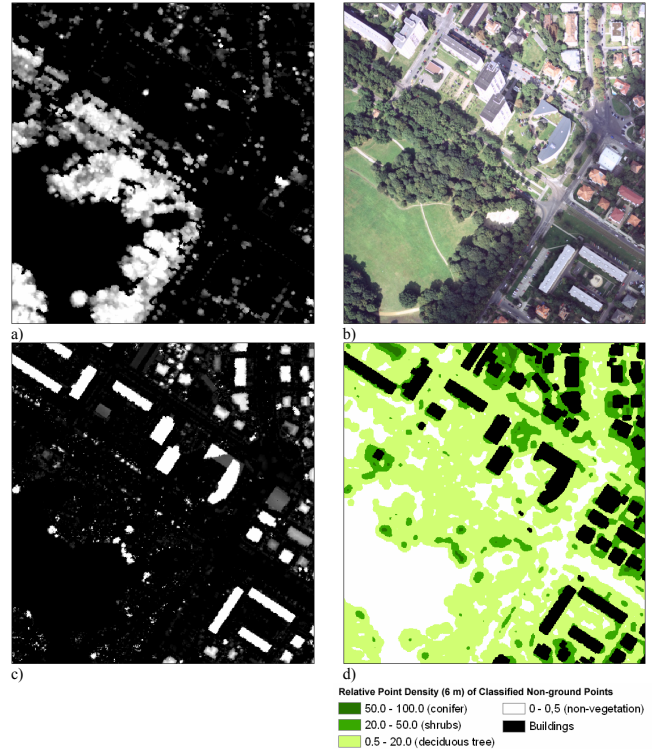

Figure 4. Study area: a) reference-nDSM b) color aerial image c) laser-nDSM d) classified point density image

The point density image represented in classes (6 m search radius; Figure 4d) shows clearly that the underestimated vegetation areas can be reconstructed. Here, the search radius correspondents to a medium crown radius of a deciduous tree. The building polygons from an external source are colored in black. This particular point density image serves further as the basis of the reconstruction.

As an alternative the point density images of varying search radii can be brought together in a way that the highest from each relative non-ground density value remain present. So after the principle of "preserving large structures of low point density and small structures of high point density" all point density images are merged to one single image that makes a sharper distinguishing of areas with high point density relations possible.

5. RECONSTRUCTION OF VEGETATION – FIRST APPROACHES

After the analysis of the laser scanner signal in vegetation stocks at leaf-off season aerial flight times the following conclusions can be drawn: the underestimation of the volume of deciduous trees is on one hand caused by the area loss of the tree crown and on the other hand by the height loss of the measured height (concerning the deciduous tree stock approx. ½ of the reference height) (Figure 5a-b). Therefore it's necessary to carry out an extensive extrapolation of non-ground points within deciduous tree stocks.

The approach is based on a point density controlled maximum filtering of the calculated nDSMs (Figure 5c). If the point density within the vegetation stock is low the radius has to be wide in order to reconstruct the vegetation (e.g. a tree).
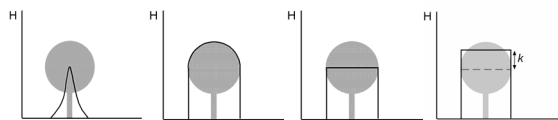
Figure 5. Schematic depiction of the signals and its reconstruction in deciduous tree stocks: a) single non-ground measurement point without correction, b) Reference model, c) Correction of the area loss, d) Correction of the height loss

If there is a high point density the surface is described well by the laser and only a small radius is applied for reconstruction. It is a simple principle which is based on the fact that the non-ground point density is a standard of the proportional volume underestimation that is again traced back to the area loss. In addition the height underestimation within the deciduous tree stock has to be compensated by a height correction factor of 44 % in average (Figure 5d).

The following approaches are possible:

- *raster-based height maximum filtering in kernel sizes depending on the point density:* The nDOM and the relative point density image of the non-ground points (see chapter 4) form the basis for selecting the extent of a following maximum filtering of height data. The precision of this approach has its roots in determining of suitable kernel sizes for maximum filtering and their controlling with two input variables (point density and height). The result of initial tests is shown in Figure 6b with the example of the oak tree without any height correction that can be realized by multiplication of height with a factor depending on height and point density.

- *point-based modelling of vegetation:* For each vegetation point that has been classified as non-ground point a circular disk with varying radius is created in dependency from the local point density and vegetation height. Figure 6 shows the creation of circular disks with the example of the oak tree. The height of the measurement point is related to each circular disk. The correction of the height loss can be carried out with a height correction factor as well. Through an afterwards vector-raster conversion the geometry including the height's data is converted into GRID. The cell data represent the local vegetation heights in a vegetation-nDSM.

a)
Height$_{max}$: 22.6
Volume: 7801 m³

b)
Height$_{max}$:12.3
Volume: 3 801 m³
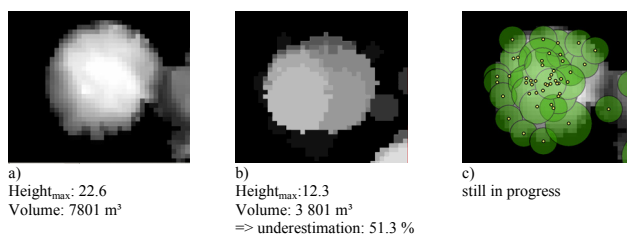=> underestimation: 51.3 %

c)
still in progress

Figure 6. a) Reference-nDSM b) reconstruction through point density-controlled maximum filtering c) vector-based point density-controlled reconstruction through circular disks

It's possible to use fuzzy logic methods by defining membership functions and the creation of rules in order to control the reconstruction with two input parameter. Both methods are being implemented at present and the results will be evaluated in comparison to reference measurements of the vegetation volume in a future work.

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