ESTIMATION OF URBAN GREEN VOLUME BASED ON LAST PULSE LIDAR DATA AT LEAF-OFF AERIAL FLIGHT TIMES

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ABSTRACT:
The estimation of urban green volume is getting more and more important within the frame of an ecologically orientated city planning. The difference of the first and the last pulse of LiDAR measurements provide the basis for the estimation of the green volume, but these optimal data are not always available. That’s why this paper deals with the question whether LiDAR data (last pulse only) that have not been taken during the vegetation period allows a sufficient estimation of the vegetation.

The work sets up on previous results where LiDAR data have been compared to photogrammetrically determined vegetation height measurements (Meinel/Hecht, 2004). The subtraction of the laser-based Digital Terrain Model (DTM) and Digital Surface Model (DSM) in vegetated areas leads to an intense underestimation of green volume of up to 85 %, which is mainly due to the standing deciduous trees with an underestimation of 90 %. Starting from the existence of different laser response characteristics within various vegetation types the relative point density and the normalized height of classified non-ground points were analysed in-depth (Meinel/Hecht, 2005). The results show a good separation within different vegetation types. Further a method of reconstruction of the underestimated vegetation is presented through extrapolation of areas with a low-density of non-ground-points and the correction of its underestimated height. The point density of non-ground-points and the normalized height of the laser responses will be the input parameter for an adaptive reconstruction. The reconstruction is carried out by generation of a cylinder for every classified non-ground point. Based on fuzzy-logic techniques with two input parameter (normalized height, relative point density) the radii and the height of the cylinder were defined. In spite of the suboptimal LiDAR data the results of the work can lead to a sufficiently exact and efficient estimation of green volume compared to the costly conventional methods like field investigations.

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, soil function index or the green volume index [m³/m²] 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 green volume a three-dimensional survey is essential necessary (Grottmann, Pohl 1984).

But there is a lack of all-covering and up-to-date information about the green volume and there are hardly city-wide applications found. In only few cases where it had been recorded, its estimation was based on the mapping of biotope type 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 stand parameters; e.g. tree height, canopy, crown surface shell and crown radius (e.g. Hyyppä, 2004, Holmgren, 2003; Hese 2002; Andersen 2001). For forestry one uses data recordings from vegetation periods of the first and the last pulse with a relatively high point density. Whereas in urban areas there are usually only laser scanner data from leaf-off aerial flight times and in some cases without the first pulse (example Dresden) since the emphasis is hereby on the creation of 3-D city models and Digital Elevation Models (e.g. for flood modelling).

Laser scanner aerial flights of urban areas during the vegetation period for estimating the green volume is desirable but considering the limited financial means of local authority districts not affordable. This leads to the question if and how existing suboptimal laser scanner data (at leaf-off aerial flight times) can be used for estimating the green volume.

Caused by a flood in Dresden in autumn 2002 the city was in serious need of an accurate DTM to simulate flooding. Therefore the whole city was captured during the following winter with an Optech ALTM 1225. The first pulse have been recorded but regrettably not processed due to the requirements of the city. Table 1 shows the technical data of the applied system.

An automated classification of the laser points was made by the company TopScan, which results in two data sets. Firstly the classified ground points and secondly the classified non-ground points, which describe all man-made objects and vegetation hits. By interpolation of the ground points a raster DTM (1 m resolution) can be derived, whereas a DSM results in using all...
laser points. By subtracting the two models (DSM – DTM) the normalized Digital Surface Model (nDSM) can be calculated, which is the basis for height measurements above the earth surface (buildings, trees, etc.).

### Technical data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner type</td>
<td>Optech ALTM 1225 (rotating mirror)</td>
</tr>
<tr>
<td>Service</td>
<td>TopScan GmbH</td>
</tr>
<tr>
<td>Flying height</td>
<td>1 000 m</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>25 kHz</td>
</tr>
<tr>
<td>Scan angle</td>
<td>12 deg</td>
</tr>
<tr>
<td>Point density</td>
<td>1.1 p / m²</td>
</tr>
<tr>
<td>Date of survey</td>
<td>12 / 2002</td>
</tr>
</tbody>
</table>

Table 1. Technical data of the LiDAR system.

In this paper, an attempt was carried out to reconstruct the underestimated parts of urban vegetation. The concept is based on previous works (Meinel/Hecht 2004), where laser response characteristics are compared to photogrammetrically determined measurements and further investigated in detail differentiated according to three main vegetation types (shrubs, conifers and deciduous trees). The results show good volume estimations for shrubs and conifers. On the other hand a low number of laser hits within deciduous trees lead to an intense volume underestimation of up to 90%. Being inspired by a good separability using the normalized height and the point density of non-ground points the idea emerges to apply an adaptive correction to the underestimated parts of the vegetation (mostly deciduous trees).

Even if it is less exact than a determination of green volume during summer season or with an available first pulse the results expected can be much more reliable than conventional area-related estimations of the green volume.

### 2. LASER RESPONSE CHARACTERISTICS IN VEGETATION

A detailed analysis of the LiDAR data compared to reference measurements is demonstrated in Meinel/Hecht 2004 and Meinel/Hecht 2005. A brief summary is given in this section.

Based on photogrammetric measurements on stereo image pairs (10 cm ground resolution) a reference-nDSM for a study area in Dresden (approximately 500 x 500 m) was created. Further, reference areas for the three main vegetation types (shrubs, conifers and deciduous trees) were defined to provide a basis for a point based as well as a grid-based comparison of the laser-model and the reference-model.

Table 2 shows clearly a deep lack of non-ground points (only 5 % of all points) within the deciduous tree stock caused by the high penetration rate during the leaf-off season. Whereas the differences in height and in volume are low for shrubs and conifers, the mean height of the non-ground points in deciduous trees is approximately 1/3 of the reference height. This is due to a high number of hits at shrub level. Further an intense volume underestimation of 90% could be found out for deciduous trees which is an effect of the deficiency in number of non-ground points (area loss) and the height underestimation (height loss).

To get a visual impression of the point clouds selected profiles are showing the reference measurements and the classified laser points for the main vegetation types (Figure 1). There are a sparse number of non-ground points for deciduous tree stock (Figure 1a), whereas the shrubs and conifers offer more densely distributed non-ground points (Figure 1b, 1c).

Getting inspired by the good separability of the three vegetation types by using the part of the non-ground points (Table 2) a more detailed point density analysis was made which follows in section 3.1.

### 3. METHOD OF RECONSTRUCTION

In this section the separation of the different vegetation types based on indicators, the principle of reconstruction and its implementation will be explained.
3.1 Indicators for point classification

Since there is a correlation between the point density of non-ground points and the density of branches (vegetation types) the attempt follows to use this information as an indicator for an adaptive correction of the nDSM. Due to the varying total point density (swath overlaps) the calculation must be the ratio of the point density of non-ground points to the total point density and is defined as relative point density [%].

\[
\text{Relative point density} = \frac{\text{point density (non-ground points)}}{\text{point density (all points)}} \times 100 \%
\]

In order to choose the right search radius the relative point density for the laser points in different vegetation types was calculated. It shows the best separation using a search radius of 6 m, which accords to the mean crown radius of a deciduous tree (see Fig. 2).

\[\text{Relative Point Density for Laser Responses within Different Vegetation Types} (\pm \text{SD})\]

Figure 2. Relative point densities in dependency of the vegetation type and different search radii.

In order to enhance the separability, the normalized height of the non-ground points should be considered to separate the understory growth with its high varying relative point density from conifers and deciduous trees. Figure 3 shows the 2D-Feature space for the different vegetation types. Shrubs beneath the canopy of deciduous trees can be seen as points with a low height (Figure 3 c). The depicted boxes show a classification within the feature space assuming sharp sets. Certainly, the classification has fuzzy boundaries, which have to be considered within the following model.

\[R = f (\text{normalized height, relative point density})\]
\[HCF = f (\text{normalized height, relative point density})\]

If there is a high relative point density the surface is described well by the laser-nDSM and no or only a small cylinder will be inserted on the nDSM. In case there exists a low relative point density starting from the non-ground point a cylinder with a large radius and a corrected height will be constructed before inserting it on the nDSM. To avoid the construction of too large radii for non-ground points at shrub level the normalized height will be the indicator for that.

It is a simple principle which is based on the fact that both indicators are a measurement for the volume underestimation.

3.2 Principle of reconstruction

As constituted in section 2, there are two essential corrections needed 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, table 2). Therefore it is necessary to carry out an extensive extrapolation of these non-ground points.

The approach is based on the construction of a cylinder for every non-ground point with the radius R to compensate the area loss. Further an application of a height correction factor HCF is needed to compensate the height loss. Figure 4 shows a schematic depiction for a small deciduous tree before and after correction. To keep the comparability to the 2.5 dimensional reference model we assume full vegetation beneath the canopy surface.

\[R = f (\text{normalized height, relative point density})\]
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If there is a high relative point density the surface is described well by the laser-nDSM and no or only a small cylinder will be inserted on the nDSM. In case there exists a low relative point density starting from the non-ground point a cylinder with a large radius and a corrected height will be constructed before inserting it on the nDSM. To avoid the construction of too large radii for non-ground points at shrub level the normalized height will be the indicator for that.

It is a simple principle which is based on the fact that both indicators are a measurement for the volume underestimation.

3.3 Fuzzy Model

Since there are two indicators regulating one output parameter (e.g. radius in dependency of the normalized height and relative point density) without having a mathematical model the fuzzy logic technique can be used to solve these sorts of problems. The fuzzy process consists of the following steps: fuzzification, definition of if-then rules, choosing of inference method and defuzzification (Mechler, 1993).

Firstly, for every indicator the membership functions (MFs) have to be defined to get it into a linguistic form (fuzzification). The MFs are composed of piecewise linear functions, which
allow a rapid calculation. Further the output (e.g. radius) will be regulated by definition of rules in terms of “if-then” conditions. Thus, the fuzzy output can be determined based on the inference method (algebraic product operator) and subsequently transformed in a sharp output value using the singleton centre of gravity method (defuzzification).

![Figure 5. Membership functions of normalized height and relative point density used for fuzzy model “Radius”.

Figure 5 shows the two indicators (normalized height, relative point density) in linguistic form and its membership functions. These and the definition of 10 output rules provide the basis for the regulation of the radius R for the cylinder. The rules are expressed like:

“IF height is low (shrub) AND relative point density is low THEN radius is 0”; “IF height is high (high tree) AND relative point density is low THEN radius is 6 m”

The same procedure of defining the membership functions and setting up the output rules are arranged to model the height correction factor.

To find out the right input, output and rule definitions statistically determined behaviours helps to understand the process to get the knowledge to create the model. The behaviour of the height correction factor could be analysed by calculating the residuals of the non-ground points compared to our reference model. The empiric determination of the behaviour radius was more complex. For that purpose 760 non-ground points where chosen and associated radii were created manually in that way, that they are compensating the area loss in proper style. It results in a 3D-behaviour matrix (x - height, y - point density, z - radius) which comprises a high ratio of noise that can be smoothed using a low pass filter. Based on these two behaviours the fuzzy models could be established. The advantage to feature it in a fuzzy model allows an easy intervention of the user to make adjustments afterwards.

Based on our reference model (see section 2) and the reference areas both models are calibrated in the way that the volume differences are minimized for all main vegetation types.

Figure 6 pictures the two behaviours of the fuzzy models “Radius” and “HCF”. The output values for the radius ranges between 0.0 and 12.0 m, whereas the height correction factor can have a maximum of 2.5.

### 3.4 Implementation

This method of reconstruction is used operationally to calculate the green volume index for the entire city of Dresden. The workflow is briefly depicted in figure 6.

Starting from the given classified laser points the relative point density (search radius 6 m) and the normalized height can be calculated for every non-ground point. Further, these value pair is the input for the two fuzzy models. The fuzzy models have been created with the fuzzy tool of the Spatial Analysis and Modelling Tool (SAMT), which is an open source project and stands under the General Public Licence (http://www.zalf.de/home_samt-lsa/index.html).

Since the output values of the fuzzy model (radius, HCF) are calculated the cylinders where constructed and inserted on the laser-nDSM. Cylinders are only constructed for non-ground points belonging most likely to the underestimated vegetation (deciduous trees).

![Figure 6. Workflow of Reconstruction.](image)

Using only the non-ground points for the reconstruction achieves relatively less data to process, which results in faster computing.
4. RESULTS

Figure 7 shows the uncorrected and corrected laser-DSM of a part of Dresden city. The bright circular discs are representing the deciduous tree stock. Further, it proves that only the underestimated vegetation is reconstructed and all non-ground points belonging to buildings do not affect the nDSM.

For an estimation of the green volume all man-made objects like buildings have to be removed from the data set. This point will be discussed below.

The study area with the uncorrected laser-DSM, corrected laser-DSM the reference-DSM and the ortho photo are shown in Figure 8. In that case, the non-ground points of man-made objects are sorted out in advance with the help of a given vegetation mask. The comparison shows the reconstruction of the standing deciduous trees in the park. The shrubs and the conifers will remain unchanged.

Figure 9 shows the same study area in a 3D-view. It shows clear visible improvements due to the application of our method of reconstruction. Nevertheless, the canopy surface at a group of deciduous trees shows still some gaps in the corrected model.

For some single trees the volume will be overestimated mainly caused by to large radii.

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Shubs (&lt; 3 m)</th>
<th>Conifer (3 - 30 m)</th>
<th>Deciduous trees (3 - 30 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference green volume</td>
<td>1.6 (0.7)</td>
<td>11.2 (4.3)</td>
<td>10.9 (5.0)</td>
</tr>
<tr>
<td>Uncorrected green volume [m³/m²]</td>
<td>1.4 (0.7)</td>
<td>11.4 (3.5)</td>
<td>0.8 (0.5)</td>
</tr>
<tr>
<td>Corrected green volume [m³/m²]</td>
<td>1.7 (1.3)</td>
<td>11.5 (4.0)</td>
<td>10.5 (6.5)</td>
</tr>
<tr>
<td>Volume difference compared to reference</td>
<td>- 0.1 (1.1)</td>
<td>- 0.3 (1.3)</td>
<td>0.4 (6.7)</td>
</tr>
</tbody>
</table>

Table 3. Comparison of the green volume for different vegetation types (standard deviation in brackets).
The intense underestimation (90 %) of the deciduous trees could be compensated through the method of reconstruction (4 %). By comparison of table 2 and table 3 the green volume for shrubs and conifer are nearly the same.

In spite of it, looking at the standard deviations, high uncertainties for deciduous trees of approx. ± 60 % are found, which is partly caused by the small reference areas.

5. DISCUSSION AND CONCLUSION

The presented method shows a high capability to realize adaptive corrections in order to improve the nDSM based on last pulse data at leaf-off aerial flight times. The results are indicating some problems (gaps, overestimations) on closer examinations. The reasons lie in the availability of the last pulse only and its deep lack of non-ground points with a correct height mainly for deciduous trees. Regarding the high uncertainties, these are found in field investigations as well caused by human errors. Further, the point density varies for different deciduous tree species, which causes different cylinder radii. Some small trees don’t have any single non-ground point and it is impossible to detect them.

To keep the comparability to our 2.5-dimensional reference model, the crown shape for deciduous trees or the existence of undergrowth is not yet considered in these calculations. For that an additional reference is needed to make accuracy assessments. However, a crown form correction can be easily implemented in the fuzzy model HCF or could be applied afterwards.

Another important role plays the vegetation mask which has a big influence on the result of the green volume estimation. The extraction of man-made objects like buildings from LiDAR data is investigated by Maas 1999, Rottensteiner & Briese 2002, etc. The problem here is that small buildings, vehicles, lanterns cannot be detected concerning the low point density of 1.1 point / m². That’s why external data like colour infrared (CIR) – ortho photos are the best option to get a reliable vegetation mask by using a NDVI-threshold.

However, keeping in mind that the main goal is to carry out block-based green volume calculations (e.g. intersection with block maps), this method shows profits using LiDAR data which are not optimal (no first pulse, leaf-off aerial flight time, no intensity data). Since conventional methods are too costly it is very beneficial to use suboptimal LiDAR data which are at least available.

6. REFERENCES


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