Evaluation of high resolution digital surface models for single tree extraction approaches in mixed forests

MOHSEN MIRI[1], STEVEN BAYER[2] & TILMAN BUCHER[3]

Abstract: High resolution digital elevation models (DEM) are utilized in automatic extraction of single-trees in mixed forests. In this paper the digital surface models (DSM) provided from aerial images with resolutions of 8 cm and 20 cm and airborne laser scanning ALS data are investigated. The results showed a relative good representation of the tree crowns even in image-based DSM. However, increasing the resolution of imagery does not inevitably lead to better quality in DSM of forests. To evaluate the characteristics of deciduous and coniferous trees on such models, two features are introduced. The Inversed Quasi-Flatness (IQF) and the Averaged Height Variation (AHV) of the DSM are implemented on some automatically selected samples at the highest levels of elevation on nDSM to demonstrate the geometric and morphologic characteristics of the different DSMs.

1 Introduction

Knowledge of tree-crown parameters such as height, shape, and crown closure is desirable in forest and ecological studies, though those parameters are difficult to measure on the ground (SHENG et al., 2001). Thanks to rapid developments in high density Airborne Laser Scanning (ALS) data and High Resolution Digital (HRD) images, both in technical and processing points of view, providing valuable geospatial information in forestry applications has increasingly become available (LECKIE et al. 2003). The necessity and the great interest in more detailed information, concerning single tree delineation and classification, especially for mixed forests, has emerged. More accurate quality and quantity information of individual trees requires detailed three dimensional positioning and accurate attributing of single trees. For this end, a normalized digital surface model (nDSM), also called canopy height model (CHM), has to be provided by subtracting DTM from DSM, which shows the importance of both DTM and DSM data in forestry areas. ALS data have proven their capabilities in capturing such elevation data. On the other side, image-based techniques, like Semi Global Matching (SGM, HIRSCHMÜLLER, 2005), can also provide good results in DSM generation in forestry. Due to the fact that the repetition rate of statewide coverage with airborne imagery is performed every 3 years, these data pose a huge and cost efficient potential for forest monitoring. For this reason LIDAR and photogrammetric DSMs are evaluated, whether or up to which extend the image-based digital surface models fulfill the forestry requests. This paper evaluates both laser-based and image-

1) Mohsen Miri, Free University of Berlin & Beuth University of Applied Science Berlin, FB III, Photogrammetry lab., Luxemburgerstr. 10, 13353 Berlin, Germany; Email: mohsen.miri@fu-berlin.de
2) Steven Bayer, Institutefor International Urban Research (InUrban), INA gGmbHat Free University of Berlin, Malteser Str. 74-100, 12249 Berlin, Germany; Email: steven.bayer@fu-berlin.de
3) Tilman Bucher, German Aerospace Center (DLR), department of Sensor Concepts and Applications, Rutherfordstr. 2, 12489 Berlin, Germany; Email: tilman.bucher@dlr.de

based DSM data at single tree level over closed mixed forests in Germany. Additionally the characteristics of the canopy height models are evaluated on automatically selected samples on the top level of the forests, using two geometric and morphologic features.

2 Image-based and laser-based data acquisition in forestry

As laser scanners can provide 3D point clouds from different heights of forest, employing the ALS data in forestry has been reaching satisfying results, even at single trees levels. In (HYYPPÄ et al. 2004) the algorithms and methods used in this area are summarized in several aspects. Along with airborne laser scanners, high resolution aerial images, as one of the basic and rich sources of detailed geospatial information for forest inventory, has been used for the relevant applications in large extend. However, image-based methods are confronted with the limitations of matching algorithms. Table 1 shows an overview of the pros and cons of both data acquisition methods in extracting geospatial attributes in forestry.

Capabilities and Potentials	**ALS**	**Imagery**
Direct measurement of the surface	✔	✖
Textural contents	!	✔
DSM generation	✔	✔
DTM generation in dense forests (or in leafy season)	✔	!
DTM generation in sparse forests (or leafless season)	✔	✔
Independence from illumination conditions	✔	✖
Costs for repeatable measurement	✖	✔
Independence from texture of the object	✔	✖
Spectral information	!	✔

Table 1: Comparison of laser-based and image-based data potential for forestry applications (potential level: ✔ high; ! medium; ✖ low).

Considering the above table, one may prefer to employ the ALS data to generate the digital elevation models, required in forestry. However, regarding the high costs of laser-based techniques, in one hand, and the richness of information in image-based methods, in the other, an evaluation of the DSM obtained from image-based is needed. It should be mentioned, that the capability of the laser-based methods to produce the point cloud of the ground under the crowns should not been unseen. As the ground surface remains more unchanged than the crown closure, typically, laser-based DTM can be used as a reference for nDSM over several years.

3 Dataset

In this paper, the image-based DSMs are generated by SGM. The first area of interest, near Hoppengarten, contains DSM generated from UltraCam XP (8 cm and 20 cm GSD) and the rasterized laser-based DSM with 40 cm GSD, acquired by LMS-Q560 from Riegl. The feature analysis is performed on the second area near the city Steinfurt using a DSM of a DMC-1 camera from the company Intergraph with 20 cm resolution and additionally the DSM of ALS data of LMS-Q560 from Riegl with 20 cm GSD. Both areas are located in state North-Rhine-Westphalia (NRW) in Germany.

4 Image-based DSM from SGM

To evaluate the image-based DSM, two sets of aerial images captured by UltraCam XP from Microsoft with 8 cm und 20 cm GSD are used. Both datasets are compared separately with DSM of LIDAR data.
Figure 1 shows a true-orthophoto of the Hoppengarten test area.

Figure 1: True-orthophoto of the test area Hoppengarten; small subset see Figure 2

For a better comparison of the tree forms in image-based and laser-based datasets, digital surface models are demonstrated in Figure 2. Although the laser data are free from noises and flying points, because of their measuring characteristics, they represent the rough and complex tree surfaces rather heterogeneous. As can be seen, the results of the SGM method, leads also to an appropriate representation of the canopy surface, though with smoother surfaces, especially in lower resolutions.

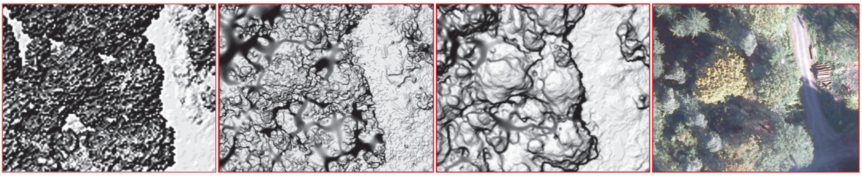

Figure 2: Test area Hoppengarten; DSM Laser 40cm, photogrammetric DSM 8cm and 20cm, RGB 8cm

A comparison between the image-based and laser-based DSM is carried out on the 8 cm and 20 cm images in this area. The differentiated images, shown in Figure 3, demonstrate well fit results (green colors) on the ground and also at the highest levels of elevation, in both resolutions. The interpolated areas, mostly demonstrated in blue colors, confirm the typical problems of stereo matching algorithms in shadowed and occluded areas. This comparison shows that although, in many cases, an increase in spatial resolution of aerial images leads to more detailed DSMs, it does not necessarily result in better surface models. Complexity of the texture on the trees, different representation in overlapping images and the illumination conditions can be named as some problematic aspects, which influence the performance of matching algorithms in forestry areas.

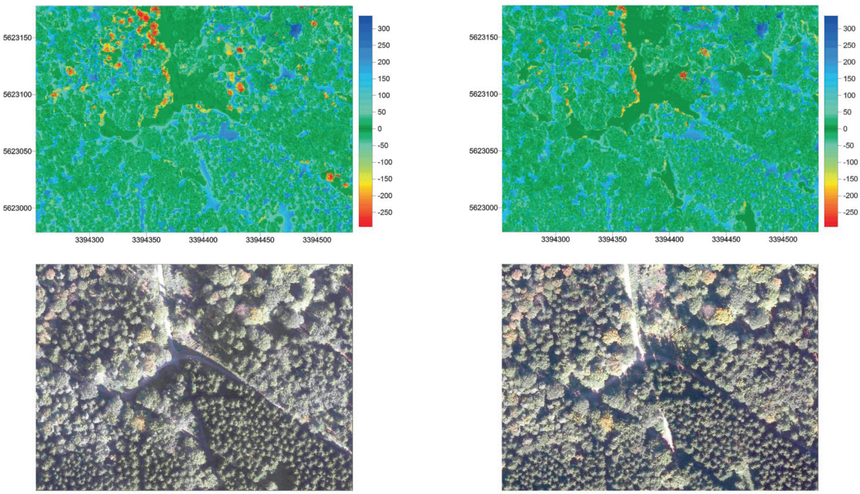

Figure 3: Top: difference images with colorized height differences in decimeter; DSM_image_8cm – DSM_LIDAR_40cm (left), DSM_image_20cm – DSM_LIDAR_40cm (right). Bottom: True orthophotos 8 cm (left) and 20 cm (right).

For the further evaluations on the second test area, the photogrammetric images with 20 cm resolution have been used. This dataset is, in our opinion, representative for a standard data type, which can be provided using SGM or similar matching algorithms.

5 Geometric and morphologic features

Due to the irregular shape of the tree crowns and the fine structure of the branches, DSMs of forested regions are difficult to generate and challenging to extract geometric and morphologic features. Coniferous and deciduous trees react differently in laser-based and image-based DSM

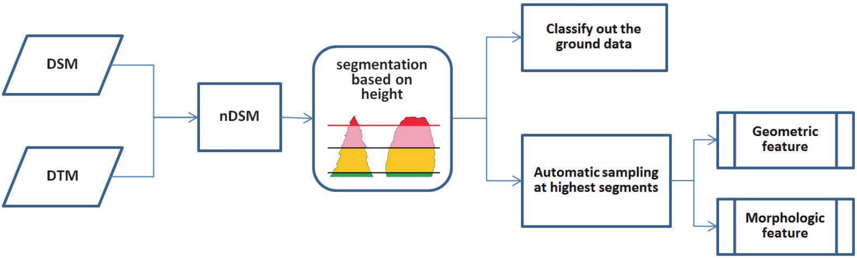

Figure 4: Processing flowchart of the feature-based evaluation of the DSM data at the level of THS (red)

data. These features can be measured using statistical parameters in order to recognize deciduous and coniferous trees; those should not be dependent on the segment height. As the locational information of the trees in remotely sensed datasets, especially on the crown, focuses mostly on their position at local maxima, the evaluation will be done at the highest levels of these datasets. The concentration on local maxima segments also avoids the critical parts of the DSM, like shaded or occluded areas between the trees. In this paper two features are defined and classified to evaluate the Top Hat Slice (THS) of the trees in several segmentation scales using a combination of pixel-based and object-based methods. Figure 4 represents the flowchart of this procedure.

In the first step, the nDSM is extracted from the DSM with 20 cm pixel size and the laser DTM of one meter (DGM-1, GEOBASIS-NRW). The next step consists of an automatic segmentation, based on the elevation data of the nDSM. This step is followed by the selection of the segments including the most significant local maxima; the top hat slices are generated. Areas below 5 m in the nDOM are classified and attributed as ground data.

For the top hat slices, two hypotheses (deciduous / coniferous) are studied, introducing two features: the *Inversed Quasi Flatness (IQF)* as geometric feature and the *Average Height Variations (AVH)* as morphologic feature. To study the reaction of these features on nDSM data the correctness of the selected samples are assessed in coniferous and deciduous stands using true-orthophotos and the terrestrial data is based on the formula employed by STRAUB (2003):

$$\text{Correctness (\%)} = \frac{\text{truely estimated segments}}{\text{truely estimated segments} + \text{false estimated segments}} \,.\, 100$$

A detailed assessment of the accuracy and correctness of the image-based DSM has been performed by BAYER et al. (2013), based on terrestrial laser scanning and photogrammetric reference data.

5.1 Inversed Quasi Flatness

Approximately, a tree can be modeled with known geometric 3D shapes by spherical, ellipsoidal or conic parameters. The IQF describes the flatness of the trees at the highest segments of the nDSM. At this level the deciduous trees are expected to be flatter than coniferous ones, which yield higher values in IQF. Figure 5 shows the color-coded results of this feature. The estimations in the laser nDSM (left) show good results for coniferous trees but relatively poor recognition of the deciduous ones. This is mainly due to the small segment size at THS level, which overestimates the IQF in this tree type. In contrast, the results in the photogrammetric nDSM show relatively good recognition of true segments in deciduous trees and lower correctness for coniferous ones (see also Table 2).

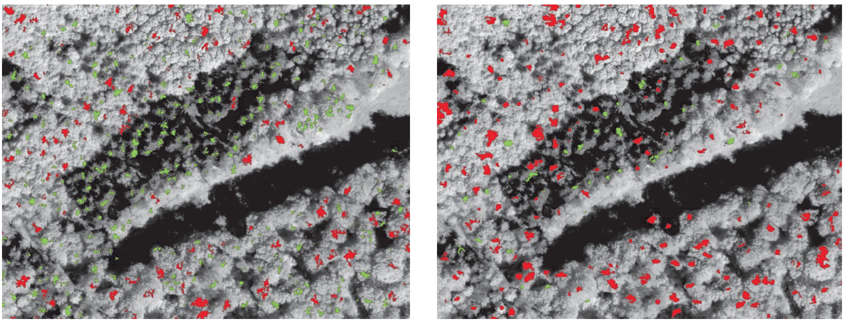

Figure 5: Comparison of IQF on laser-based nDSM (left) and image-based nDSM (right) at low segmentation level for ■ coniferous and ■ deciduous tree types.

5.2 Averaged Height Variations

The second feature, AHV, is provided to measure the averaged variation of height at the THS level. Comparing the coniferous and deciduous trees in leafy season, it is expected that the latter react with more scattered values on the upper surfaces but less height variation among the segment.

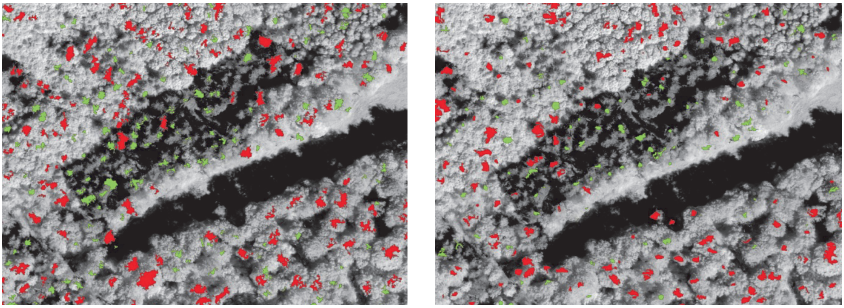

Figure 6: Comparison of AHV on laser-based nDSM (left) and image-based nDSM (right)at low segmentation level for ■ coniferous and ■ deciduous tree types.

As seen in Figure 2 LIDAR data exhibit strong local variations. These are reduced in the first steps of segmentation on ALS data using a 3x3 median filter to avoid the oversegmentation. The results show that coniferous trees are correctly detected and decreasing the segment size leads to better detection of these tree types. On the other side, due to the characteristics of the laser data, more detailed segments decreases the generally low detection probability of deciduous trees. In image-based nDSM the capability of this feature to separate deciduous trees seems to increase with smaller segment sizes.

nDSM	Segmentation detail level	Stand type	IQF (%)	AHV (%)
Laser-based	Low	Coniferous	88.09	85.71
		Deciduous	63.79	50
	High	Coniferous	98	98.43
		Deciduous	37.62	25.74
Image-based	Low	Coniferous	52.38	78.57
		Deciduous	94.74	24.56
	High	Coniferous	70	91.25
		Deciduous	68.478	41.30

Table 2: suitability of the IQF and AHV on laser-based and image-based data

6 Conclusions and Outlook

High resolution DSM generated from laser-based and image-based techniques are evaluated in different resolutions. Comparing two photogrammetric DSMs, a higher resolution lead to a more detailed DSM, however due to the limitations in stereo matching algorithms such as occlusion and shadows, the results especially in forests did not improve significantly. Therefore the standard resolution 20 cm has been used for further investigations. To evaluate the characteristics of deciduous and coniferous trees in the models, two features have been introduced to measure the flatness and roughness value of the DSM data in automatically selected segments at top head slices. The results show that both features work properly in coniferous stands. However the deciduous trees react differently. Because of the different morphology of the two tree types, in on hand, and the stand density, in the other, separation of the trees into different feature-classes is necessary. This can exemplarily be seen in Table 2, where the accuracy of the deciduous trees is much higher than for the coniferous trees, which depends on the segment size. This effect can be used for the classification of deciduous trees without spectral information. After classification of deciduous ones, the remaining trees can be extracted with smaller segment sizes and smaller search radius for detecting the local maxima. This results in a higher accuracy in recognition of the deciduous trees, too. Further works will be done to optimize the parameters for these features in and also the on the preprocessing steps of laser and photogrammetric DSMs.

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