Low altitude LiDAR and TLS point clouds for improved tree detection

M. Hirschmugl[1,2], H. Fellner[3], R. Wack[4], G. Bronner[3], M. Schardt[1]

[1]Joanneum Research, Steyrergasse 17, 8010 Graz
Email: {manuela.hirschmugl, mathias.schardt}@joanneum.at

[2]University of Graz, Heinrichstrasse 36, 8010 Graz
Email: manuela.hirschmugl@uni-graz.at

[3]Umweltdata, Knabstraße 7/4, 3013 Tullnerbach
Email: {h.fellner; g.bronner}@umweltdata.at

[4]Aeromap, Niederöblarn 83, 8960 Niederöblarn
Email: r.wack@aeromap.at

1. Introduction

The background of the contribution is the proposed 3-stage forest inventory (Bronner et al., 2018), which involves a third data level between the well-known wall-to-wall airborne laserscanning (ALS) data and the similarly well-known terrestrial laser scanning (TLS) data. We call this intermediate data layer “low altitude laser scanning” (LALS), as it is acquired from an ultralight airplane at low flying altitude and with a tilted sensor to allow a slightly oblique viewing angle. This constellation resulted in a point density of 400 points/m². Previous work on similarly high resolution data has reported high accuracies (Dersch et al., 2021) in managed forests, while we apply this system in a forest, which is currently in transition to a continuous cover forestry (CCF) management system. CCF is a nature-based solution (NBS) system, which relies on single tree harvesting and near-natural species and age mixtures to pertain a resilient and still productive forest (Burschel und Huss 1997, Schütz 2001, O’Hara and Gersonde 2004, Pretzsch 2006).

The research questions tackled in this study are

1) How well do existing approaches perform in areas of CCF?
2) How well can different approaches be combined to achieve better accuracies?
3) How can the different information sources be merged to generate added value?

2. Data and Methods

2.1 Data

The LALS data was acquired at a flying altitude of about 150 m above ground level. The sensor, a Riegl VUX240, was tilted backwards at an angle of 20°. Each strip was flown in both directions with 1.8 MHz at an average speed of 125 km/h. This led to a point density of approximately 200 pts/m² per overpass resulting in a total point density of approximately 400 pts/m². An example of the acquired point cloud is shown in Figure 1. The data shows a lot of detail and at the forest edge (Fig. 1) or in open stands, also the individual stems are visible.

Published in: Markus Hollaus, Norbert Pfeifer (Eds.): Proceedings of the SilviLaser Conference 2021, Vienna, Austria, 28–30 September 2021.
Technische Universität Wien, 2021. DOI: 10.34726/wim.1861
This paper was peer-reviewed. DOI of this paper: 10.34726/wim.2003

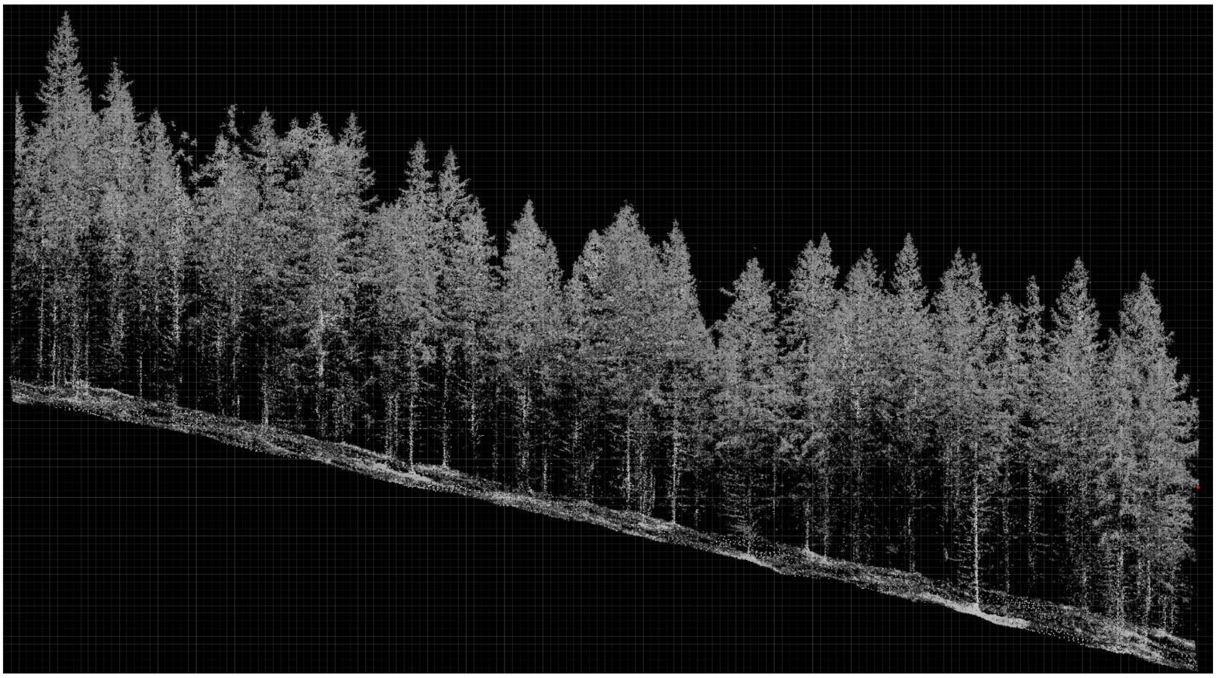

Figure 1: Point cloud of LALS data.

TLS data was acquired using a Riegl VZ-400i during the vegetation periods in summer 2020 and 2021. In 2020, only one scan position per plot was used, in 2021, per sample plot, 10 to 15 scan positions were recorded without artificial tie-points. The co-referencing of scan-positions was calculated by RiScan Multi-Station-Adjustment. The resolution during scan acquisition was 40x40 mdeg, which produces several million points per 360° scan. The point clouds where filtered with regard to the deviation, reflectance, range and isolated points. The TLS tree detections of 2020 were done using OPALS (https://opals.geo.tuwien.ac.at/). The TLS tree detections for TLS data of 2021 were done by Forest Design (www.forestdesign.ro). For reference purposes, 151 trees were measured in the field. The measuring was done in 18 plots by measuring the centre point of each plot with GPS and using distance and azimuth to calculate the individual tree positions. This procedure resulted in a rather low tree location accuracy, which has to be taken into account when evaluating the results. The low number of reference trees is a result of the angle count sampling with a k-factor of four, which means that every sample tree represents four square metres per hectare. This means, that smaller trees were only measured, if they were located very close to the plot centre. Table 1 summarizes the TLS and field measured tree locations.

Table 1. Tree counts used for comparison.

Source	Software	No. of plots	No. of trees	Available infos
TLS 2020	OPALS	6	683	Position (TLS), DBH
TLS 2021	Forest Design	1	1884	Position (TLS), DBH, estimated height, volume and species
Field work	-	18	151	Position (GPS center coordinate & distance & azimut)

2.2 Methods

The methods used in this work consist of both, existing and well-established methods like tree top detection from nDSM data (Hirschmugl et al., 2007) as well as of further developments of most recent advancements, like the Bird's Eye View (BEV) method (Windrim and Bryson, 2020) and their combination. For eliminations of double-detections, Python-based scripting was used. The overall workflow is depicted in Figure 2.

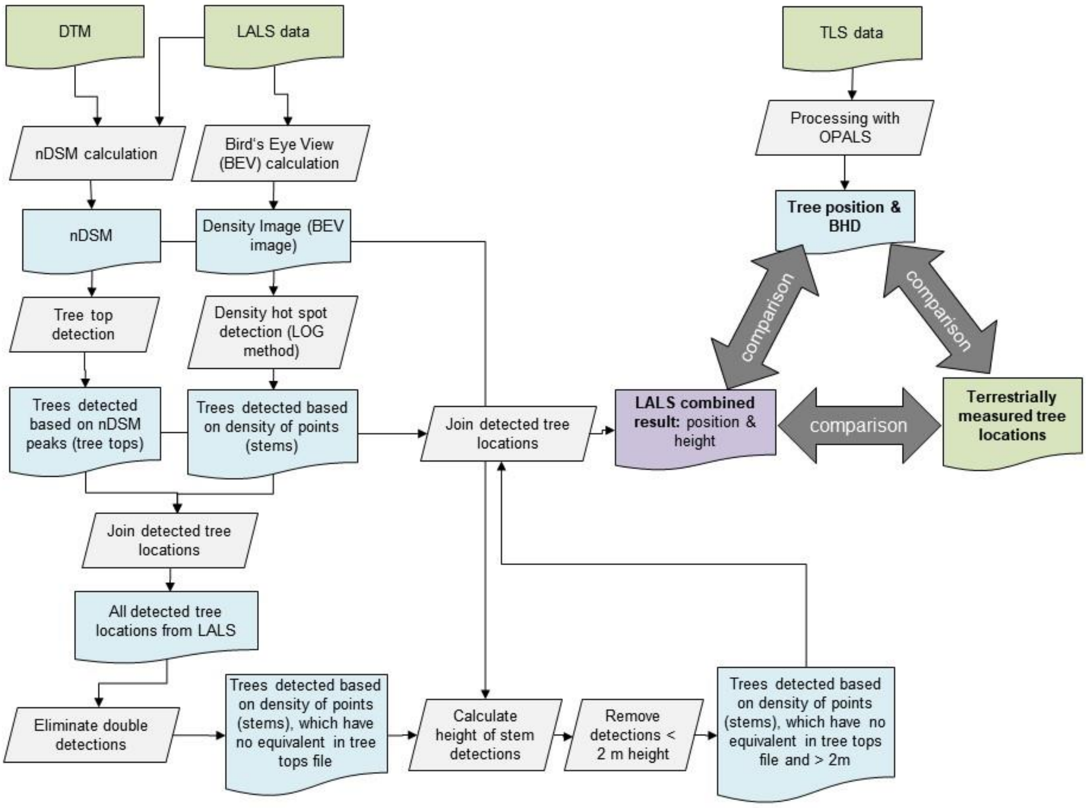

Figure 2: Workflow.

In the first step, an nDSM is calculated from the LALS data and an existing DTM. This nDSM at a resolution of 0.5 m is used to detect tree tops. In parallel, the LALS data alone is used to calculate the so-called Bird's Eye View (BEV), which is basically the density of LiDAR returns per spatial entity. A regular grid of 10 by 10 cm was used to calculate this density. In previous works, this BEV image showed the stems as bright blobs (Windrim and Bryson, 2020), circles or semi-circles due to the high density of returns at the stem (Dalla Corte et al., 2020). In the BEV image of our CCF, the stems are not well depicted and unfortunately, the BEV image does not show any circle-like objects potentially useable for stem detection (compare Figure 3 and Figure 7). However, the BEV image does show the crown and main branches as areas of higher density (Figure 3). This higher density can be interpreted in the same way as higher nDSM values and can thus be treated with the same approaches. The LOG method (Hirschmugl, 2008) was used for this purpose.

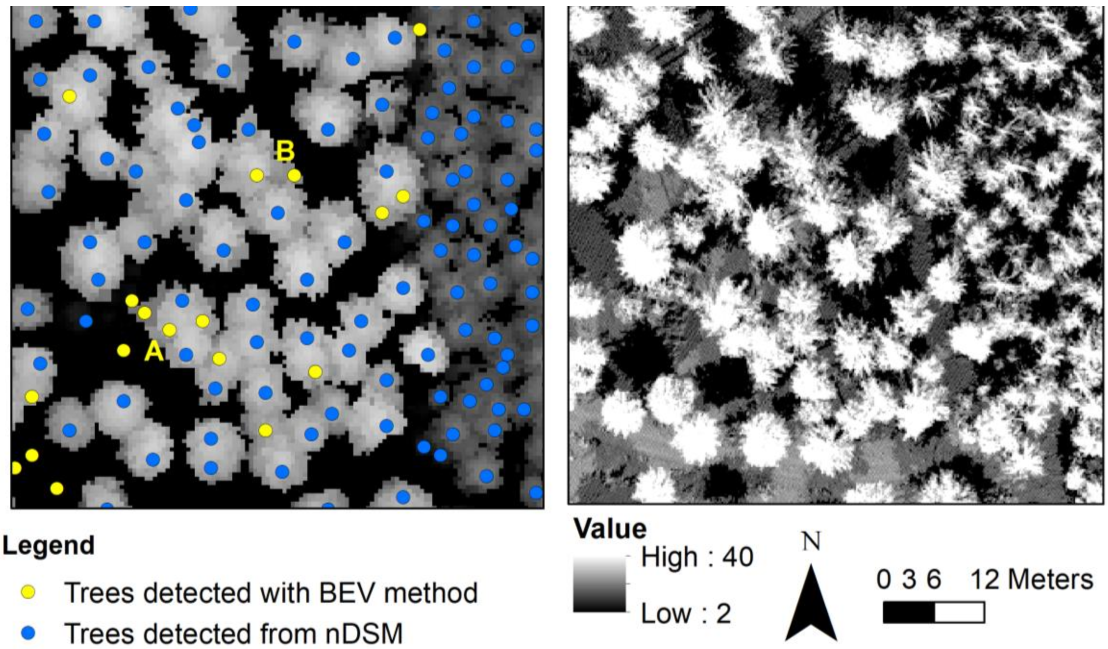

Figure 3: Comparison of nDSM-based results (blue) and additional BEV-based results (yellow). The gray values in the background images (2 – 40) represent height above ground in m (left) and number of LiDAR returns per pixel (right)

In order to avoid multiple detections of the same tree, we decided to retain only those BEV detections, which lack an nDSM equivalent. These additional detections and the advantages are shown in Figure *3* The BEV method allows detecting individual trees in a patch of deciduous trees, which were considered as one tree in the nDSM method due to missing distinct maxima in height (Figure *3*A). Further, small trees between or under larger trees can be detected by the BEV method (Figure *3* B).

3. Results and Discussions

The comparison of the results with the field measurements (Figure *4*) shows, that the inclusion of the BEV data allows detecting trees, previously not found with the nDSM approach alone, such as small, understory trees (Figure 4 A) or individual deciduous trees (Figure 4 B). In addition, small trees neither captured by the nDSM approach, nor covered in the field measurement (due to the high k-factor), but visible in the data, could be detected with the BEV approach (Figure *4* C). All 151 field measured trees were detected with the combined nDSM/BEV approach. The assessment of omission and commission error is not possible with this ground truth data, as the field measurements are not a full assessment, but only a count sampling with k-factor 4.

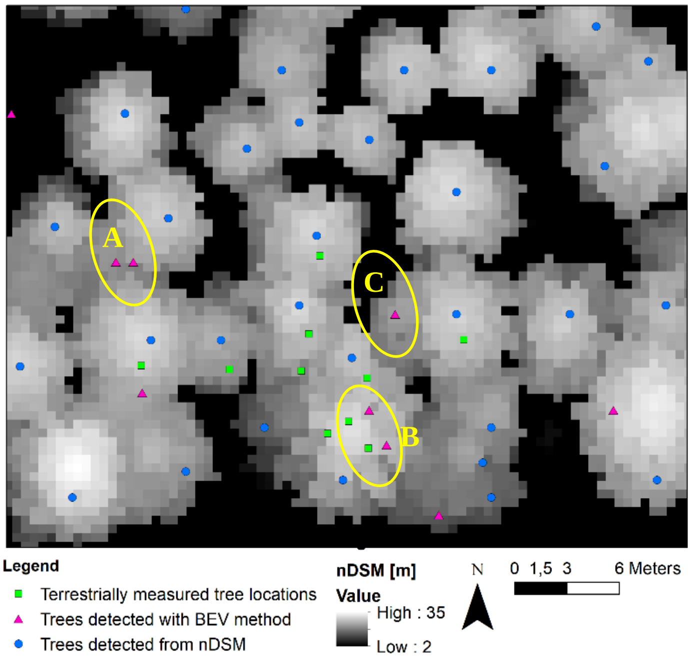

Figure 4: Results of the LALS tree detection approaches (BEV, nDSM) compared to field measurements.

Due to the limitations of the available field measurements, we compared the combined results also to TLS measured tree locations. The TLS tree locations were manually adjusted to match the nDSM due to the originally inaccurate GPS-based geolocation. The two data sets show a very good agreement for all the main trees (see **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 6: stars = TLS-based tree locations, points = combined LALS tree locations). There are also LALS detections, which have no equivalent in the TLS measurements (**Fehler! Verweisquelle konnte nicht gefunden werden.** A&B). The trees in **Fehler! Verweisquelle konnte nicht gefunden werden.** (A) may be very small trees, which were either not covered with the TLS or could also be commission errors in the LALS data. Tree detections marked in **Fehler! Verweisquelle konnte nicht gefunden werden.** with (B) are probably missing in the TLS detections due to occlusion by other trees. This theory is supported by the location of to the only scan position. However, there are also some omission errors compared to the TLS measurements; see **Fehler! Verweisquelle konnte nicht gefunden werden.** (C).

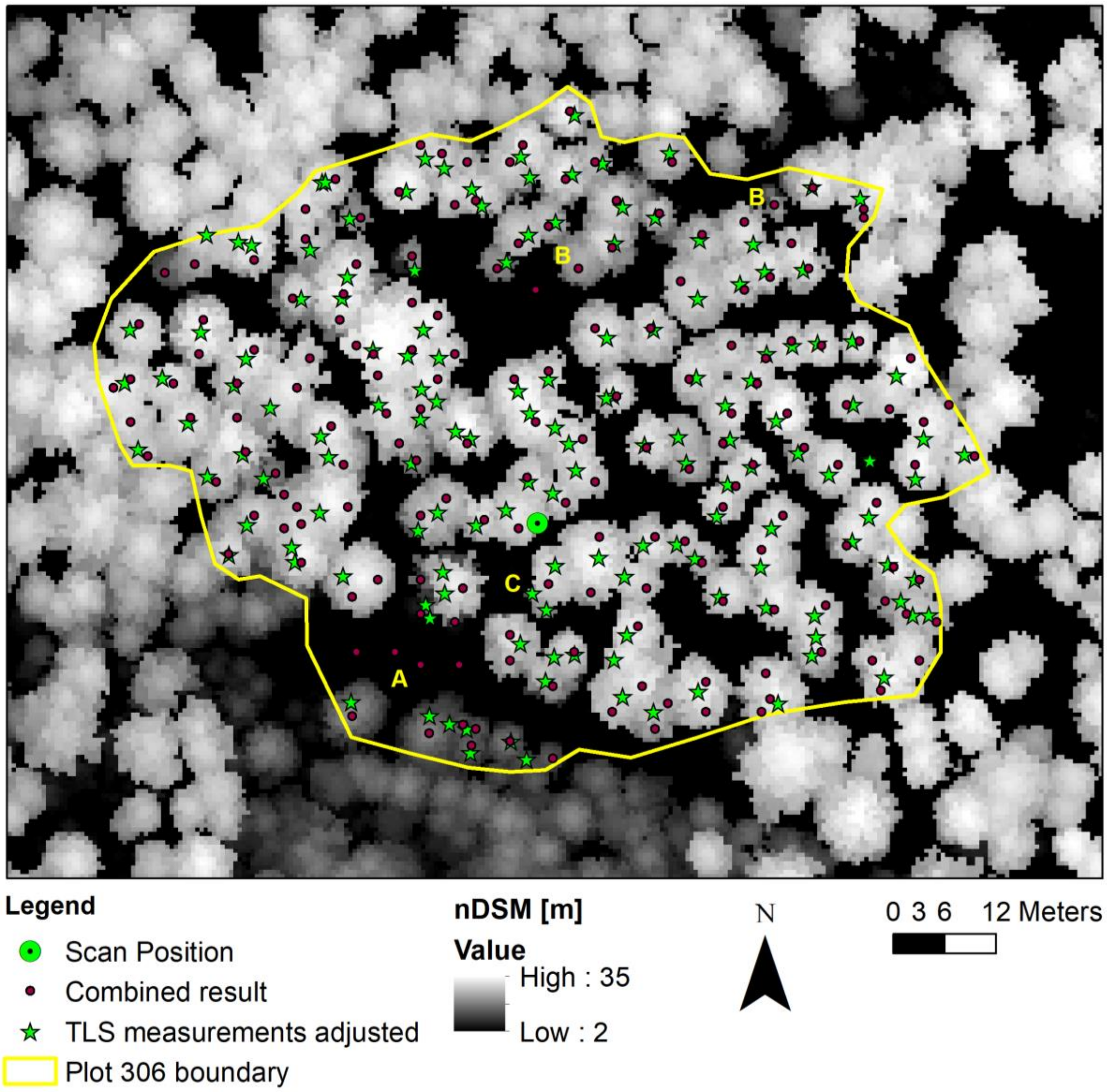

Figure 5: Results of the LALS tree detection compared to TLS measurements 2020 using OPALS.

Another comparison was done using results from the second TLS scan campaign done 2021 with multiple scan positions and the processing chain from Forest Design (FD, for more details see www.forestdesign.ro). This approach detects much more trees, but we could not verify the results in the field so far. Figure 6 compares the results of TLS FD with the combined LALS results. There is a general good agreement of both data sets in rather open stands (A). In areas marked with (B), there are many more stems detected from the TLS data than from the LALS data, which could be correct, especially in young forest areas. However, more field work or visual interpretation of the point cloud is needed to verify this assumption.

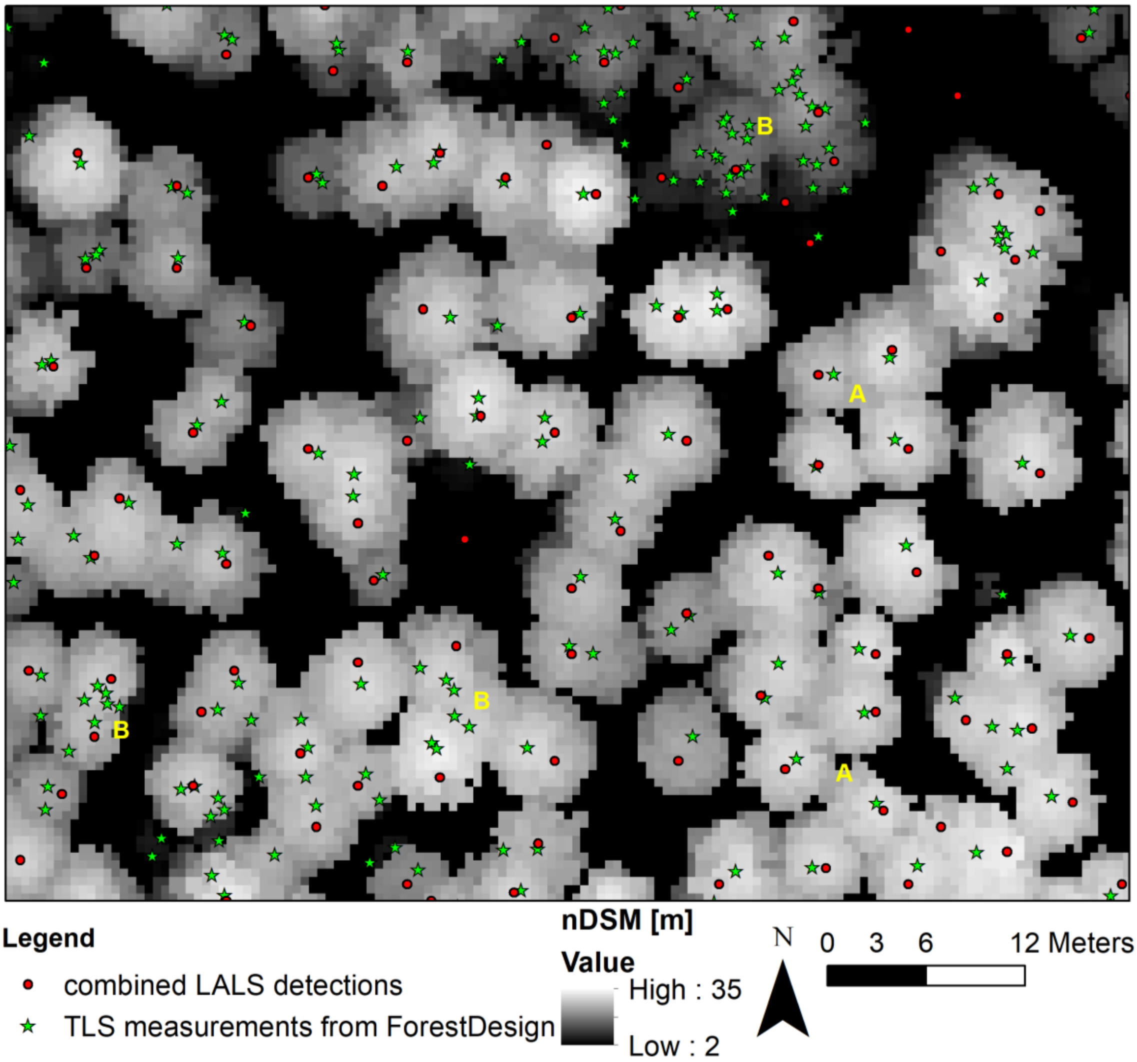

Figure 6: Results of the LALS tree detection compared to TLS measurements using FD.

The next logical step is the combination of TLS and LALS results. This will be further studied, once a proper automated geolocation of the TLS data is achieved. The combination will allow combining the height information from the nDSM with the DBH measured by the TLS and the derivation of the stem axes of the individual trees.

Aside from the TLS and LALS combination, future work is threefold. The first part covers a better use of the BEV images. A segmentation of the BEV image into 2m height intervals, as shown in Figure 7, is expected to allow crown base estimation and will be tested in a deep learning approach to further improve tree detection. A new field campaign including a full assessment will allow to calculate both the commission and omission errors. In the frame of this exercise, we will also look specifically at deciduous trees. The third part is to compare and combine the LALS data with standard ALS data to work out the mutual benefits and ideal combination possibilities.

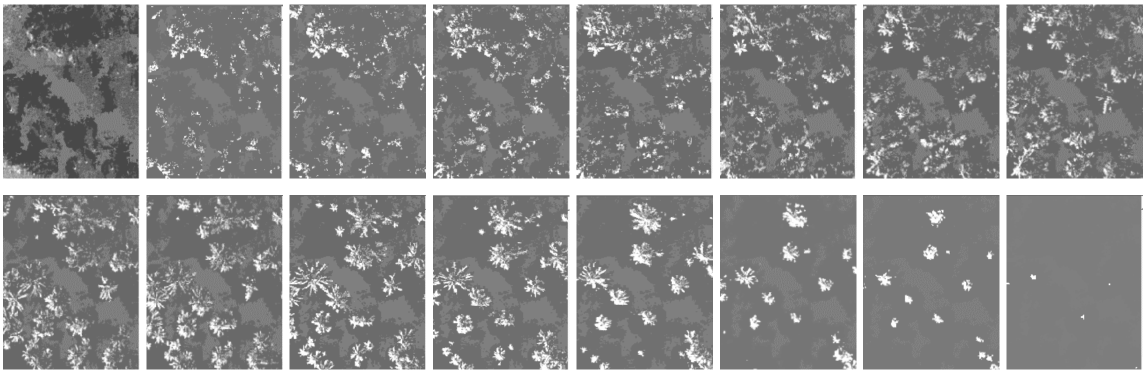

Figure 7: Vertical distribution of LALS points in 2 m interval from ground level up to 32 m

5. Conclusions & Outlook

This study shows that LALS data is suitable to detect most major trees confidently. Combining different tree detection approaches resulted in the better detection of small, partly understorey trees and individual stems in deciduous forests. However, most recent results from TLS data analysis suggest, that still small trees are omitted. This needs to be verified in the field. Once, proper geolocation accuracy of the TLS measurement is achieved, the automated combination of LALS tree position and TLS data will further add to the amount of detected trees and to the number of available forest parameters by providing for example the diameter at breast height (DBH) or even species. The next steps include the assessment of the crown base from LALS data, the comparison with standard ALS data and the combination of all levels (TLS, LALS and ALS) into a complete system.

Acknowledgements

This study received funding from the Austrian Research Promotion Agency (FFG) in the frame of the COIN network “DeepDigitalForest”.

References

Burschel P. und Huss J., 1997. Grundriss des Waldbaus, Kapitel 6.1.3 S. 108 ff, 2. Neubearbeitete und erweiterte Auflage Parey Bucherverlag Berlin ISBN, 3-8263-3045-5

Dalla Corte, A.P., Rex, F.E., Almeida, D.R.A. de, Sanquetta, C.R., Silva, C.A., Moura, M.M., Wilkinson, B., Zambrano, A.M.A., Cunha Neto, E.M. da, Veras, H.F.P., Moraes, A. de, Klauberg, C., Mohan, M., Cardil, A., Broadbent, E.N., 2020. Measuring Individual Tree Diameter and Height Using GatorEye High-Density UAV-Lidar in an Integrated Crop-Livestock-Forest System. Remote Sensing 12, 863. https://doi.org/10.3390/rs12050863

Dersch, S., Heurich, M., Krueger, N., Krzystek, P., 2021. Combining graph-cut clustering with object-based stem detection for tree segmentation in highly dense airborne lidar point clouds. ISPRS Journal of Photogrammetry and Remote Sensing 172, 207–222. https://doi.org/10.1016/j.isprsjprs.2020.11.016

G. Bronner and M. Hirschmugl and R. Wack and B. Jawecki, 2018. Three Phase Forest Inventory Design with 1) wall-to-wall ALS, 2) very dense ALS on sample stripes and 3) fieldwork sample plots. Presented at the FORESTSAT 2018, Maryland.

Hirschmugl, M., 2008. Derivation of Forest Parameters from UltracamD Data (phdthesis). Graz University of Technology.

Hirschmugl, M., Ofner, M., Raggam, H., Schardt, M., 2007. Single tree detection in very high resolution remote sensing data. Remote Sensing of Environment 110, 533–544.

Windrim, L., Bryson, M., 2020. Detection, Segmentation, and Model Fitting of Individual Tree Stems from Airborne Laser Scanning of Forests Using Deep Learning. Remote Sensing 12, 1469. https://doi.org/10.3390/rs12091469