ANALYSIS OF FULL-WAVEFORM ALS DATA BY SIMULTANEOUSLY ACQUIRED TLS DATA: TOWARDS AN ADVANCED DTM GENERATION IN WOODED AREAS

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ABSTRACT:

Airborne laser scanning (ALS, also referred to as airborne LIDAR) is a widely used data acquisition method for topographic modelling. In archaeology, it has revolutionised prospection of forested areas. Here, especially full-waveform (FWF) ALS systems show considerable advantages for the generation of digital terrain models (DTM) in vegetated areas, as the FWF-information (e.g. echo width) can improve classification of ALS data into terrain and off-terrain points, resulting in greater DTM quality and higher potential for the subsequent archaeological interpretation. FWF-ALS displays a high potential, but is still in its infancy (in contrast to conventional ALS sensors FWF-ALS is just available since a few years). One key topic to be investigated is the complex interaction of the laser beam with different types of vegetation cover. An in-depth understanding of the FWF-information is essential to enhance the quality of the DTM and to allow a reliable automated interpretation of the acquired data. To study the interaction of ALS and the resulting FWF-information with a vegetation complex, part of a forest was scanned by airborne and terrestrial laser scanning (Riegl LMS-Q680 and Riegl VZ-400). The combined data acquisition took place simultaneously on a calm day. Using tachymetry, the data sets were geo-referenced and the differences between the ALS and TLS data sets were minimized by an adjustment using planar control and tie patches. Based on the TLS dataset, the position of the derived ALS echoes are studied and the additionally derived FWF-parameters are investigated. This analysis allows increasing the knowledge about the interaction of the laser beam with different surface elements and allows to estimate the potential for methods for advanced DTM generation. Based on this knowledge a high quality DTM can be determined which allows an advanced interpretation of archaeological structures which are present on the terrain surface.

1. INTRODUCTION

In the last years, airborne laser scanning (ALS, also referred to as airborne LIDAR (light detection and ranging)) became a widely used data acquisition method for sampling of the topography. The resulting 3D data provides a good basis for modelling the ground surface with or without objects (houses, trees) and is utilized in several different application areas, e.g. hydrology (Mandlburger et al., 2009), city modelling (Rottensteiner and Briese, 2002) and forest mapping (Naesset, 2007). ALS especially excels in forested areas due to the fact that an active direct 3D sensing principle is utilized (for the estimation of one point on the illuminated surface only one line of sight is necessary). Small footprint ALS systems can penetrate the vegetation layer through small gaps in the canopy and therefore may allow receiving an echo from the terrain surface even in densely vegetated areas.

This advantage of ALS in vegetated areas and furthermore the increasing capabilities of ALS sensor systems (increasing point density with more than 1 point/m²) has also revolutionized archaeological prospection of forests. Due to the availability of country wide ALS data the study of extended archaeological landscapes becomes possible. However, to successfully apply ALS for archaeological prospection, special demands have to be met during data analysis (Doneus and Briese, 2010).

After geo-referencing of the acquired observations, the result of an ALS data acquisition campaign is a (strip wise) unstructured and unclassified 3D point cloud (often enriched by additional attributes like echo ID, echo intensity or amplitude, GPS time, etc.). This point cloud can be utilized for visualisation purposes, but for an advanced use of the data there is usually the need for further analysis and classification. All of the application areas mentioned have typically in common that a classification of the ALS data into terrain and off-terrain points is essential.

For archaeological prospection, the terrain points and the resulting digital terrain model (DTM) are of vital importance. Here, the separation into surface and object points has to be of high quality, because errors can easily lead to misleading interpretations. Other applications, like city modelling, biology or forestry are especially interested in the identification of

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objects (e.g. cars, buildings, individual trees, or brushwood) within the point-cloud.

In any case, sophisticated classification is necessary. For the extraction of a DTM, various algorithms were developed (cf. Briese, 2010). All of them have in common that they study the local geometric properties of the acquired ALS points. Other information, which could help to improve classification, is rarely utilized.

With the advent of full-waveform (FWF)-ALS systems (Hug et al. 2004, Wagner et al., 2004) additional interesting observables for an advanced classification of the FWF-ALS data have become available. Doneus and Briese (2006) demonstrate the advanced capabilities of FWF-ALS data for the generation of digital terrain models (DTM) in vegetated areas. The echo width determined from the FWF information was used to support the classification of the ALS data into terrain and off-terrain points in the presence of low vegetation. Mücke (2009) extended the utilisation of the echo width by introducing a weighting scheme that depends next to the increase of the echo width on the echo amplitude. In both examples, utilizing information from FWF-ALS could improve the quality of the estimated DTM.

FWF-ALS therefore seems to be a very promising approach to enhance the quality of both DTMs and digital object models (DOM). However, it is still in its infancy. In contrast to conventional ALS sensors FWF-ALS is just available since a few years and extended processing chains still have to be developed. Especially the complex interaction of the laser beam with different types of vegetation cover has to be better understood. Enhanced knowledge in this field, i.e. an in-depth understanding of the FWF-information will improve both quality and reliability of DTMs. This is especially desirable in areas with low vegetation. Furthermore, the investigations should lead to advanced geometric models that allow a more reliable automated analysis, which is desirable for different applications (hydrology, etc. as well as archaeology).

This paper can be seen as a first step towards a detailed study of the interaction between FWF-laser beams and various objects within a vegetation complex. For the analysis a vegetated area was simultaneously scanned by airborne and terrestrial (TLS) laser scanning on a calm day. After presenting the study area, we will focus on the process of co-geo-referencing the ALS and TLS data sets. In section 4 and 5, some preliminary results of the analysis of the FWF-ALS data set are presented and discussed.

2. STUDY SITE AND DATA ACQUISITION

For the study of the FWF-ALS data, a small area (approx. 2.25km², cf. Figure 1) was selected in the Leithagebirge, approx. 30km south of Vienna. This area is already well known by the authors due to a small FWF-ALS mission in 2006 (Doneus and Briese, 2006) and a large archaeological FWF ALS data acquisition campaign carried out in 2007 (cf. Doneus et al, 2008). It contains a large building complex of a former monastery ("St. Anna in der Wüste") in the central northern part. The buildings are encircled by an open meadow which is enclosed by a forest with understory of varying density.

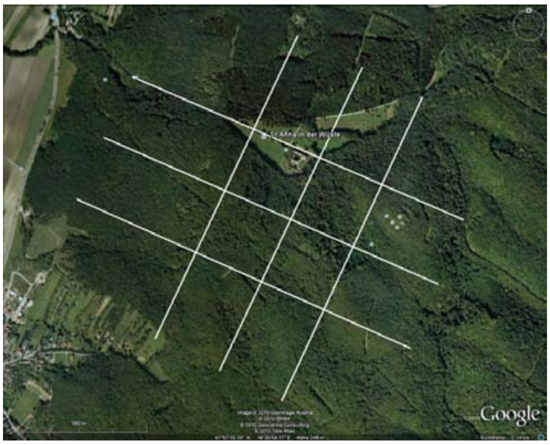

Figure 1. Study Site "St. Anna in der Wüste" in the area of the Leithagebirge (30km in the south of Vienna) with the planned flight lines (approx. length: 1.5km) for the ALS data acquisition. © Google 2010

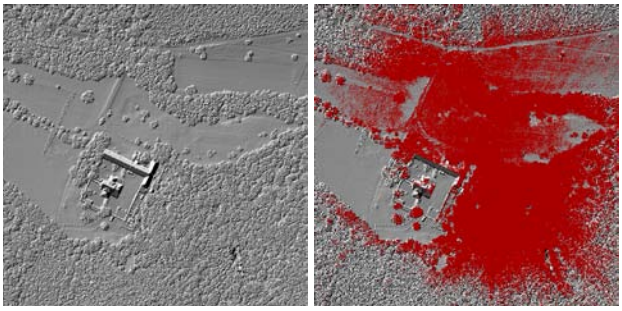

Figure 2. Left: Shading of a digital surface model (DSM, 0.25m raster) of the main area of interest (370m by 370m) derived from the ALS data; Right: DSM shading and TLS data (red).

The data acquisition of the site took place on the 10th of December 2009 in leaf off condition. It was a day with no wind. This was important to exclude the effect of wind on the vegetation canopy and facilitate the co-registration of the simultaneously performed TLS and ALS scans. The FWF-ALS data set was acquired during a test flight of the company RIEGL Laser Measurement Systems GmbH with the novel FWF-ALS sensor RIEGL LMS-Q680 (Riegl, 2010). The area was covered by six strips (both three strips in perpendicular directions) with a flying height of approx. 500m above ground. This resulted in an ALS point density of approx. 20 last echo points/m². A shading of the resulting digital surface model is displayed in the left part of Figure 2.

The TLS data acquisition took place simultaneously to the ALS flight. The TLS data was acquired by a Riegl VZ-400 instrument with online waveform processing capability (cf. Riegl, 2010; Pfennigbauer and Ullrich, 2010). Additionally to the TLS data, images were acquired by an attached digital camera (Nikon D300). Altogether, data from 16 stations were acquired near the north eastern part of the monastery (cf. right part of Figure 2). For an advanced geo-referencing of the ALS and TLS data (see section 3), some of the stations covered the monasteries' inclined planar roof areas with different exposition. Furthermore, reflector targets were used in order to perform a relative orientation/registration of the individual stations.

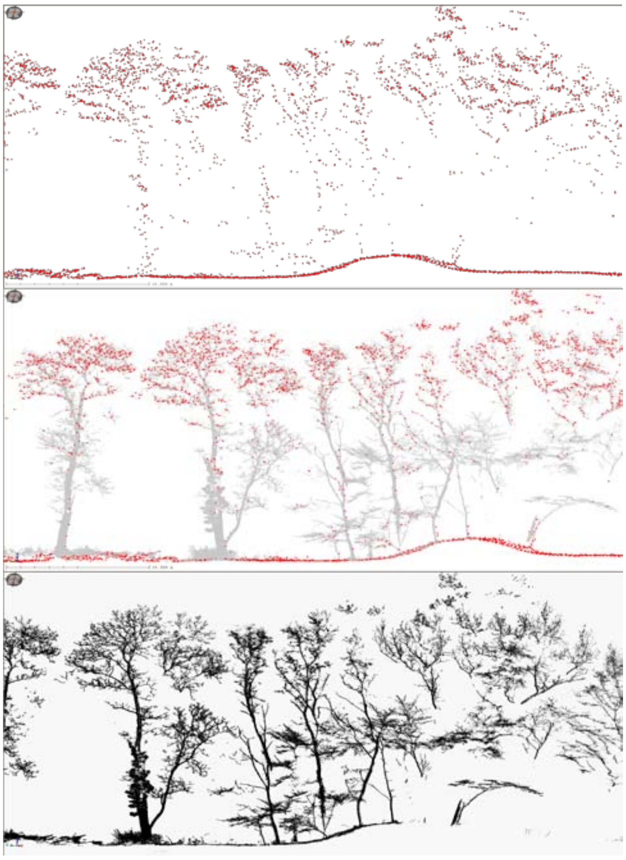

Figure 3. Visualisation of the geo-referenced ALS and TLS point cloud; Upper part: ALS points (red); Middle part: ALS (red) and TLS (grey) points; Lower part: TLS points (black).

For the absolute georeferencing of the ALS and TLS data, 28 of the reflector targets were observed by a total station (Leica TPS 1200). Additionally, the total station was used to measure points within the scanned roof areas in order to determine pass patches for the absolute position and orientation of the scan data. All in all, points on six different roof faces (visible in the ALS and TLS data) were observed.

3. GEOREFERENCING OF ALS, TLS AND TACHEOMETRY DATA

For the study of the simultaneously acquired ALS and TLS data, an adequate geo-referencing of the data sets is essential. For all of the following steps the commercially available Riegl software package (RiANALYZE, RiPROCESS and RiWORLD) was used (Riegl, 2010).

As a first step, a decomposition of the acquired FWF-ALS data set was performed. This includes the detection of all echoes per emitted laser pulse and for each echo the determination of a model in order to derive further echo parameters (amplitude and echo width). For geo-referencing, the trajectory of the airplane has to be determined using the observations from the global navigation satellite system (GNSS) and the inertial measurement unit (IMU). Based on the trajectory in the global co-ordinate system, the detected echoes in the scanner co-ordinate system (SOCS), and the mounting information, the co-ordinates of all echoes can be derived by direct geo-referencing. However, due to the requirements of the study, an advanced geo-referencing of the ALS data was essential. Therefore, based on the absolutely determined roof faces and additional planar tie elements, a strip adjustment of the ALS data was performed (Kager, 2004, Riegl, 2010). Within this adjustment, the differences to both the planar pass and tie patches were minimized

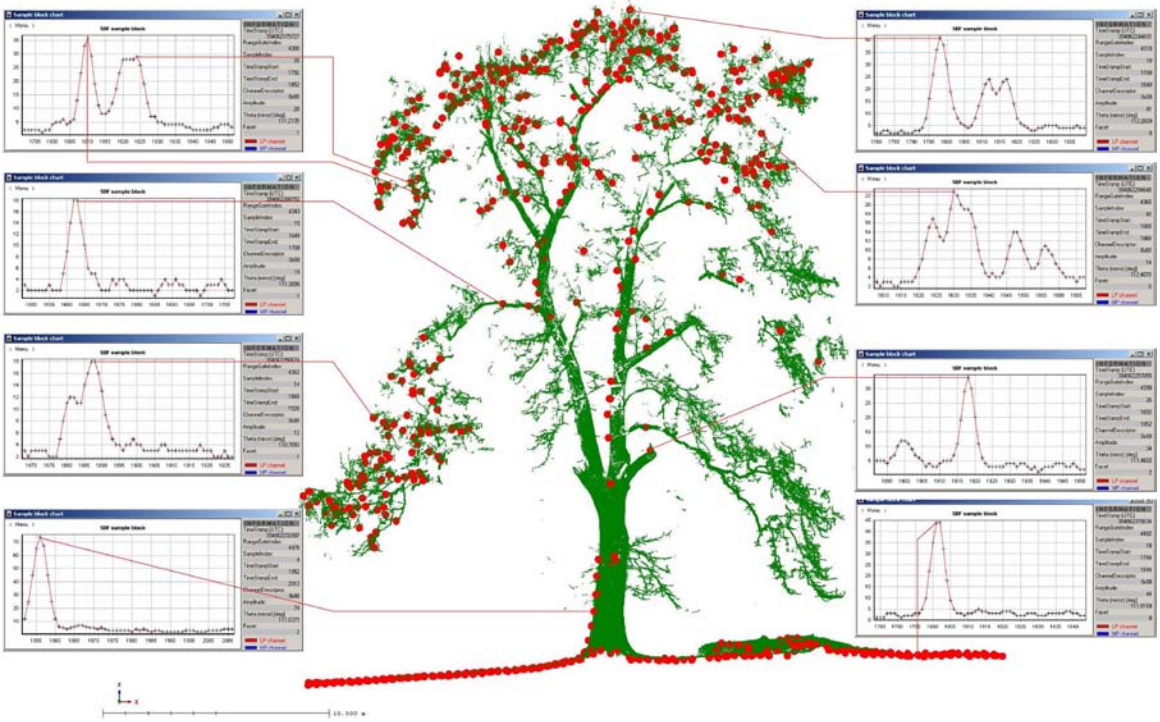

Figure 4. Inspection of the FWF-ALS data (red points) and recorded waveforms by the TLS point cloud (green).

The data of the 16 TLS stations was automatically co-registered using asymmetrically distributed reflectors. The total TLS point-cloud was geo-referenced using 28 absolutely determined reflectors within the Riegl software RiScanPro (Riegl, 2010).

As a result both data sets were finally geo-referenced in the Austrian co-ordinate system GK-M34. This process of geo-referencing could be checked by the comparison of identical surfaces that were observed by ALS and TLS (e.g. some roof faces). Additionally, any possible presence of errors can be inspected by a 3D visualisation of both ALS and TLS point clouds. This is, however, impractical: due to the high point density, individual ALS and TLS points can hardly be recognized. Only profile views with clipped point clouds were suitable to visually inspect the resulting merged point cloud. As displayed in Figure 3, the ALS and TLS data set fit well together (the tree trunks and branches are located at the same position in both data sets). No discrepancies could be detected visually. However, a quantitative study of the accuracy has to be done as a future step in the project.

4. ANALYSIS OF THE FWF-ALS DATA

Based on both geo-referenced data sets, the position of each individual FWF-echo together with the derived FWF-parameters can be studied. This analysis should allow to increase the knowledge of the interaction of the laser beam with the different surface elements. Based on these studies, we see further potential for advanced classification for DTM generation and object separation.

In the first step of the analysis, individual ALS points can be viewed together with the recorded respectively digitised waveform, while the context of the object is provided from the TLS data (see Figure 4). In Figure 4, the ALS-derived terrain points below the tree follow the terrain points of the TLS data set and have a very narrow echo width. The same is true for those ALS points, which have been reflected from the lower stem. ALS points, which are visible on the main branches, coincide perfectly with the TLS points. This emphasizes the high quality geo-referencing of both data sets. When looking on the respective waveforms one can typically find one strong echo resulting from the extended target at the tree surface. When looking at the echo width a slightly broadened echo (caused by the locally sloped surface) can be found.

On the smaller braches on top of the tree typically more than one echo (up to five) can be seen in the waveform display. Some of the echoes are very close or even overlaid. Some of the echo widths are broadened, especially in areas with very dense and thin branches. Concerning the vertical ALS point distribution one can see that the top canopy layers are very densely covered and that many of the ALS echoes are located on thin but dense branches.

All in all the (big) tree is represented well in the ALS point cloud, just small branches below the very dense canopy layer are not covered by ALS points. Holes in the TLS data are caused by shadow or by the profile selection.

In order to study the sequence of echoes that are the result of a single emitted laser pulse, 3D visualisations with connecting lines were generated (Figure 5). In the upper part of Figure 5 ALS echoes that result from the same line of sight are connected by a grey line. In the middle part of the figure the FWF information (in this case split into two graphs) of the selected line of sight can be inspected. It can be seen that the echo amplitude of the tree echoes caused by the tree top differs significantly. While the second echo is quite weak (just a little bit above the detection threshold) the third echo is even stronger than the first. This might be explained by the vegetation density. It seems that the third echo results from a thicker branch than the first echo, while the second echo must be caused from a very small branch. In the second graph of the FWF information one can see that the first local maximum that is visible in the FWF signal was not accepted in the echo detection step due to its low amplitude. The amplitude of the detected fourth echo is also very low (even lower than the second echo). The last echo of this line of sight has the highest amplitude and my result from an extended target (compare lower part of Figure 5).

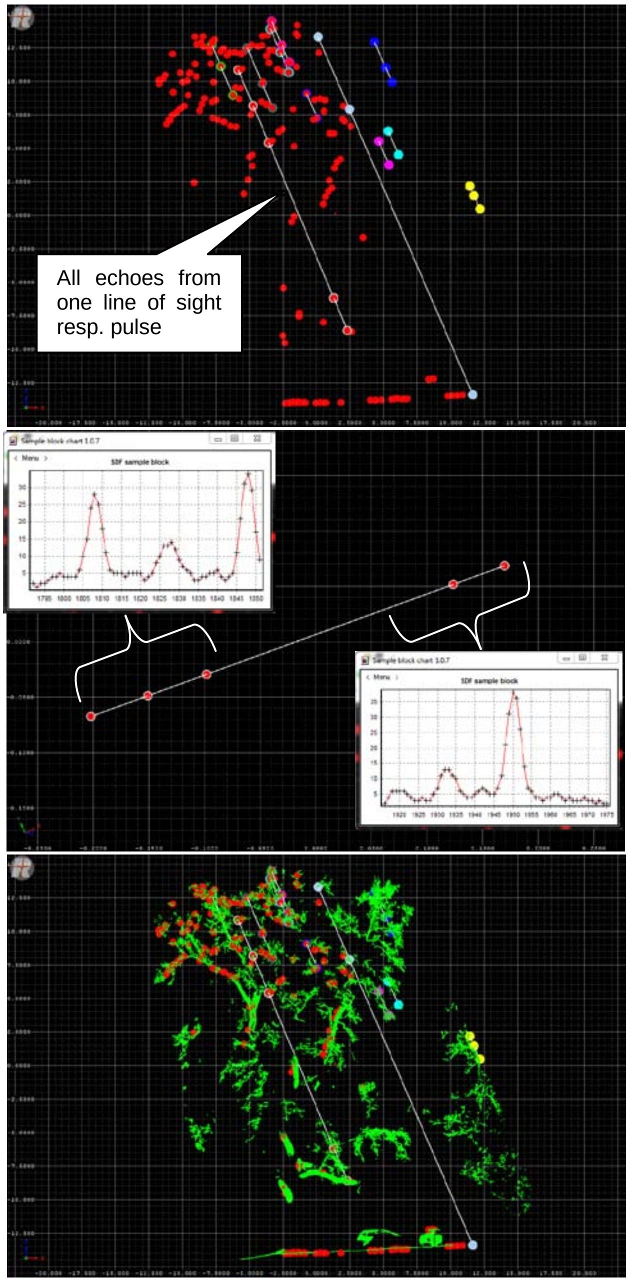
All echoes from one line of sight resp. pulse

Figure 5. Inspection of all FWF-ALS echoes from one line of sight (red points) and TLS point cloud (green).

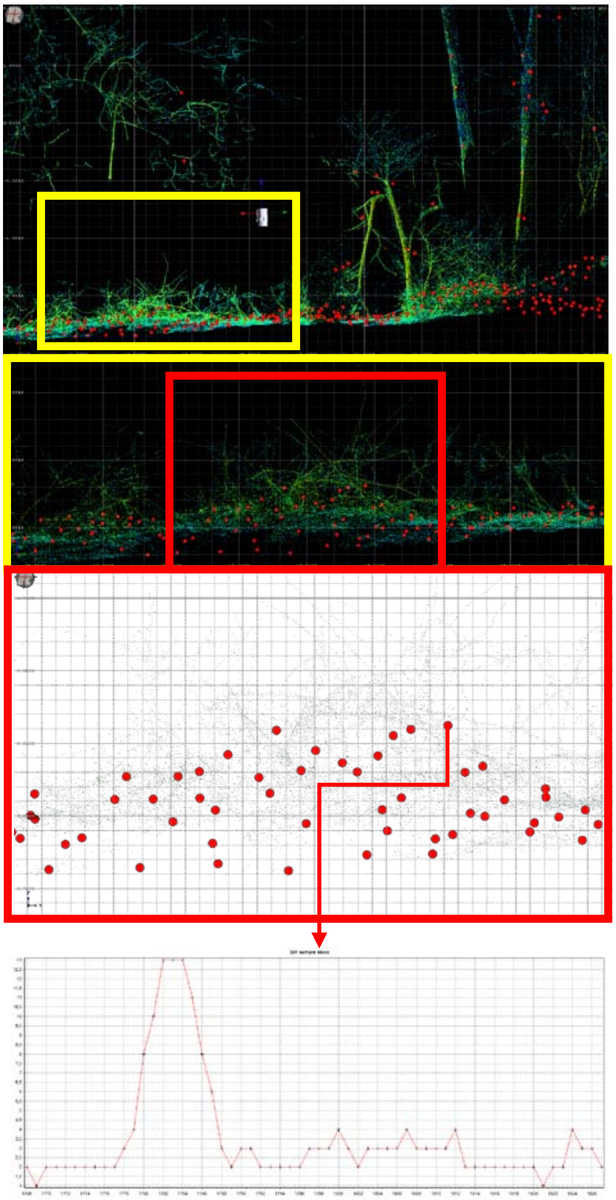

Figure 6. Inspection of FWF-ALS echoes in vegetated areas with dense understory (red points) and TLS point cloud (green).

Next to the examination of the echoes that belong to one line of sight, the influence of low vegetation on the FWF information is analysed. One example for this study is displayed in Figure 6. In the upper part of the figure dense brushwood can be found below a tree (marked by a yellow rectangle). In the middle of the figure a more detailed view of the understory area with the red ALS points attached on the TLS observations can be found. In the lower part of the figure the digitised FWF information for one representative ALS point is displayed in a graph. Compared to other echoes from planar extended targets (compare for example the echoes of the tree trunk in Figure 4) it can clearly be seen that the understory leads to an enlarged echo width. This increase of the echo width is caused by the reflection of a sequence of small reflecting surface elements at different heights and provides therefore a good basis for the automated detection of influence of these low vegetation cover on the resulting ALS points. In these areas, points that are affected by understory will typically lie slightly above the terrain. Without the additional knowledge from FWF-ALS these points are very difficult to classify as off-terrain echo points and might therefore often influence the run of the terrain surface in a negative way. FWF-ALS with its ability to determine the echo width has a high potential to perform an improved classification of the ALS data in these areas with dense understory and offers the potential to derive an advanced DTM.

5. CONCLUSION AND FUTURE WORK

As ALS constantly finds new fields of application, special demands are increasingly made on the results. Archaeology for example needs a high quality separation of terrain and off-terrain points to derive detailed DTMs displaying micro-topographic variation even under forest canopies. Biology and forestry are interested to extract individual trees from the point-clouds. During the last years, FWF-ALS turned out to have a high potential to meet many of these requirements. However, an in-depth understanding of the FWF-information is essential to enhance the quality of the DTM and to allow a reliable automated interpretation of the acquired data.

This paper aimed to start the investigation of the complex interaction of the laser beam with different types of vegetation cover. Part of a forest was scanned by airborne and terrestrial laser scanning (Riegl LMS-Q680 and Riegl VZ-400). The combined data acquisition took place simultaneously on a calm day. Using tachymetry, the data sets were geo-referenced and the differences between the ALS and TLS data sets were minimized by an adjustment using planar control and tie patches.

The investigation of each individual FWF echo together with the derived FWF parameters and the digitised waveform could be done within the context of the object that is provided from the TLS data. In that way, we could gain interesting results especially from densely vegetated areas, which will help to improve algorithms for the advanced usage of FWF information.

In the future we want to quantify the accuracy of the geo-referencing of the ALS and TLS data in more detail. Furthermore, we aim to study the interaction of the laser beam with the terrain and the attached objects by further advanced visualisations (e.g. by the direct visualisation of the FWF signal and the FWF parameters in the 3D view).

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