UAV BASED LiDAR ACQUISITION FOR THE DERIVATION OF HIGH-RESOLUTION FOREST AND GROUND INFORMATION

Felix Morsdorf a, Christoph Eck b, Carlo Zgraggen b, Benedikt Imbach b, Fabian D. Schneider a, Daniel Kükenbrink a

a Remote Sensing Laboratories, University of Zürich, Winterthurerstrasse 190, 8057 Zurich, Switzerland – felix.morsdorf@geo.uzh.ch
b Aeroscout GmbH, Technikumstrasse 21, 6048 Horw, Switzerland – [eck.zgraggen,imbach]@aeroscout.ch

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ABSTRACT:

Laser scanning of forested areas helps to analyse and understand various aspects of forest conditions, including distribution of plants and trees, height distribution of trees, tree density, size and volume of wood, as well as ground surface properties. However, laser scanning of forest area is also very challenging due to many reasons. Best time for scanning is before leafing-out in spring time or after trees cast its leaves in autumn before snow fall. This will allow the UAV (unmanned aerial vehicle) laser scanner to penetrate the forest from the top of the trees down to the ground surface. In order to receive highly accurate laser data and high point density, the flight planning must be adjusted judiciously. Flight planning will be even more complex in steep terrain where the UAV cannot operate at constant altitude. This paper discusses a UAV-based 3D laser data recording – LiDAR scanning – of forest area with high accuracy and point cloud resolution. In addition, the point cloud of airborne laser scanning (ALS) is compared with local terrestrial laser scanning (TLS) results. The forest area consists of mixed forests containing varying tree sizes and branch deformation. This paper summarizes our latest results in UAV-based LiDAR acquisition over forest area to extract detailed forest and ground information and finds that UAV-LS is well suited for provision of both high-quality forest structural and terrain elevation information.

1. INTRODUCTION

The performance of UAV-based laser scanning has shown remarkable results during the last decade including ground surface scanning, electrical powerline and vegetation scanning as well as scanning of various ground objects (e.g. bridges, buildings, daylight mining area, etc.). Various results have been published already and are well documented on websites (e.g. www.aeroscout.ch). Beside the mechanical and electrical integration of a laser scanner on the Aeroscout Scout B1-100 UAV helicopter, the flight performances of the UAV itself as well as the mission planning are challenging tasks in order to achieve accurate and homogenous point clouds. In forestry area the demands on the point cloud density are even more challenging with up to 1000 pts/m². This high point density will be required in order to allow identification of major tree branches, determine tree diameters, i.e. tree diameter breast height DBH, and accurate wood volume estimates. However, there are various challenges before, during and after data recording described below.

While section 1 describes the UAV system itself and the payload integration, section 2 concentrates on the mission planning requirements. Also mission execution is shortly described in section 2. Section 3 concentrates on the data processing combining trajectory data from the inertial measurement unit (IMU), the Global Positioning System (GPS/GLONASS) and the differential GPS station with the recorded laser scanning data. All data recording was performed on board in full resolution and is being downloaded after flight for further post-processing. Sections 4 & 5 go into detail of forest and ground surface data analysis. The airborne laser scanning data is also compared and supplemented with terrestrial laser scanning data. This terrestrial laser scanning data was recorded in an accessible wilderness area with multiple positions. Section 6 of the paper gives some conclusions and also summarizes the major results. The Acknowledgement and a list of publications complete the paper.

1.1 UAV helicopter

The industrial Scout B1-100 UAV helicopter produced by Aeroscout GmbH, Switzerland is a fuel-driven helicopter with 100ccm two-stroke fuel engine, providing a standard customer payload capacity of 18kg and a flight endurance of 1.5 hour. The standard lift-off weight is 77kg (incl. payload 18kg, fuel 9kg, FCS 3kg, batteries & data link 3kg, mechanics 44kg). The Scout B1-100 UAV helicopter is equipped with a flight control system powered with redundant batteries and independent from the customer payload. The photography of the Scout B1-100 UAV helicopter is shown in Fig.1, showing the helicopter during the laser scanning flight over forestry area. The helicopter has a rotor diameter of 3.2m and communicates with the ground control station (GCS) over several digital data links. Due to the classical helicopter configuration, the scanning performance and homogeneity of data collection in continuous forward flight are superior to multirotor aircraft, in particular under changing wind conditions (wind gusts, side wind, etc.). The flight performance of the helicopter is superior to
experienced helicopter pilots and automatic landing within sub metre accuracy is possible.

1.2 LiDAR payload integration

The LiDAR payload as shown in Fig. 2 combines the OXTS xNAV550 IMU/GPS dual-GPS-antenna navigation solution and the RIEGL VUX-1UAV laser scanner. Time-synchronization is based on GPS provided by the IMU/GPS unit. The data interface for both units has been realized with the Aeroscout “Airborne Laserscanning and Monitoring Integration (ALMI)” software running on the ground control station. The ground control station (GCS) communicates with the LiDAR payload using a WLAN network data link. Before starting the engine of the helicopter for warming up, on the one hand the GPS reference station has been initialized to determine the exact absolute GPS reference position. Afterwards the differential correction data is also stored at the GCS. On the other hand the LiDAR payload itself is being initialized. After lift-off a circular flight pattern does improve the angular precision of the IMU/GPS navigation unit during climb up.

Figure 2: Airborne Laser Scanning and Monitoring Integration (ALMI) of a RIEGL VUX-1 laser scanner with the OXTS xNAV550 IMU/GPS dual-antenna navigation unit.

2. MISSION PLANNING

2.1 UAV flight pattern

In order to achieve the high-resolution point cloud the flight meander are spaced at 20m. Due to the steep terrain, the flight lines are executed with continuous climb rate along the mountain. In order to achieve optimal ground penetration of the laser scanner, the flight altitude above the tree canopy has been reduced to 20...30m. This does also allows having sideward laser scanning data from the mountain side which will further increase point density. Reducing the flight altitude was possible because there is a laser scan of the area from a previous flight, so the altitude of the trees was known very precisely. The overall flight pattern is shown in Fig. 3. This screen shot was taken during the flight and shows the mission profile and the UAV status during the flight.

Figure 3: Mission planning and mission execution during the laser scanning flight. Multiple flight lines with continuous climb rate allow the helicopter to follow the forest surface along the hilly area.

The cruising speed was set to 4m/s based on the point density requirements. During the turns, the cruising speed of the Scout B1-100 UAV helicopter was slightly reduced. The variation of the power requirements during the flight were well indicated by the throttle percentage. These power variations were due to wind conditions along the mountain area above the forest canopy and also due to wind turbulences while sunlight is warming up the forest area in the morning. During the 30 minutes of the flight, the manual backup pilot remains in line-of-sight of the UAV helicopter as required by the Swiss Aviation Authority BAZL.

2.2 Configuration of the LiDAR payload

The RIEGL VUX-1UAV laser scanner has been set to an opening angle of 240 degrees with a scanning rate at 550 kHz. Based on the nominal altitude above ground level of 80m and a cruising speed of 4m/s, this yields a point density of about 230pts/m² for one scan line. Table 1 summarizes the settings of the LiDAR payload.

<table>
<thead>
<tr>
<th>Nominal flying height above ground</th>
<th>80 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal flying height above tree canopy</td>
<td>30 m</td>
</tr>
<tr>
<td>Spacing between flight lines</td>
<td>20 m</td>
</tr>
<tr>
<td>Scanning area</td>
<td>12 ha</td>
</tr>
<tr>
<td>Scanning rate</td>
<td>550 kHz</td>
</tr>
<tr>
<td>Opening angle</td>
<td>240 deg</td>
</tr>
<tr>
<td>Point density</td>
<td>230 points/m²</td>
</tr>
<tr>
<td>Point spacing</td>
<td>0.06 m</td>
</tr>
</tbody>
</table>

Table 2: Summary of the laser scanning mission.

3. DATA POST-PROCESSING

The processing of the laser data was done with the RIEGL software package RiPROCESS. The raw laser data is combined with the position and attitude data collected from the time synchronized onboard IMU/GPS navigation sensor to get the 3D point cloud. Multiple flight lines with overlapping data allow for adjusting the laser data strips to improve the accuracy of their relative registration.

3.1 Trajectory processing

The IMU/GPS unit xNAV550 from OXTS comes with its own processing software RT Post-Process. The software first downloads the recorded raw data from the unit and stores it in the specified folder. The recorded differential GPS file can be selected, together with the desired processing settings. For this flight, the trajectory was processed with a high GPS weighting and forward and backward calculations. After processing, the trajectory can be checked in RT View which is part of the processing software. It is then stored with the correct time representation, in this case it is UTC time. With that, the processing of the trajectory is finished and it is ready to be combined with the laser scanning data.

3.2 Laser scan processing

As preparation for the processing of the laser data, the raw laser data file is cut into scan lines with the help of the RIEGL tool.
4. SITE AND VALIDATION DATA

4.1 Site description

The Laegeren site is located at N47°28'49'' and E8°21'05'' at 682 m a.s.l. on the south slope of the Laegeren mountain, approximately 15 km northwest of Zürich. The south slope of the Laegeren marks the boundary of the Swiss Plateau, which is bordered by the Jura and the Alps. The western part is dominated by broad-leaved trees, mainly beech (Fagus sylvatica L.) and ash (Fraxinus excelsior L.). In the eastern part beech and Norway spruce (Picea abies (L.) Karst.) are dominant. The forest has a relatively high diversity of species, ages, and diameters and the ground cover consists of bare soil, boulders, and litter, while existing understory is characterized by a dense herb and shrub coverage. Average canopy height is 24.9 m, with a maximum of 49 m (numbers from airborne laser scanning), and the stem density is 270 stems per ha (derived from forest inventory). A core site of 300 m by 300 m has been subject to intensive ground and airborne measurement campaigns. Starting in 2010, the Laegeren site has been subject to intensive field campaigns, including single-tree forest inventory, spectroradiometric measurement and terrestrial laser scanning. Within the University of Zürich, the Laegeren is being used as a core testsite for calibration, validation and prototyping of remote sensing methods, data and products. Remote sensing data acquired includes laser scanning and imaging spectroscopy data, and ranges from some millimeter cm to 300 m in spatial resolution. Together with the field data, an excellent experimental setup for cross- down- and upscaling is provided.

4.2 Terrestrial and airborne laser data for cross-comparison

Traditional airborne laser scanning (ALS) leaf-on and -off datasets were acquired in 2014, using a Riegl LMS-Q680i with a maximum scan angle of ±22 deg resulting in an average echo density of about 15 points/m2. The DTM was provided by the data supplier, and was created using the TerraScan software suite. During the same day of the UAV laser acquisition, a ground-based, terrestrial laser scanning (TLS) survey was carried out, using a Riegl VZ1000 instrument. A total of 40 scans on 20 scan locations in a area of roughly 60 m by 60 m in size were taken. About 50 reflective targets were placed within the scene, to be later used for co-registration of the scans. The single-scans were co-registered using RiScan Pro and the UAV data was subsequently globally adjusted to the unified TLS point cloud. It should be noted that there was absolutely no wind on that day, greatly facilitating matching even of finer branches.
5. RESULTS/SECTION

5.1 Comparison with airborne laser scanning

Figure 5: Airborne laser scanning point cloud from 2014 (top) and UAV based laser point cloud from 2017 (bottom) on a transect encompassing the flux tower. Note that the tree to right has been removed in 2017. The gray scale color coding is used to show the intensity information.

Figure 5 shows a comparison of the UAVLS point cloud (bottom panel) with the operational ALS dataset of Kanton Aargau (top panel), whose nominal point density was > 4 echoes per meter square (actual for the subset shown is 15/m²). The UAV-LS has more than 3200 points per meter squared. It clearly shows much more details for trees and branches, including the structures comprising the flux tower. But as well the ground information is much denser and the measurement accuracy is in the order of a couple of cm, as was established using the roof of a forest hut as a reference (image not shown).

5.2 Comparison with terrestrial laser scanning

Figure 6: UAV-LS point cloud (cyan) and TLS point cloud (gray scale) from the recent survey.

Figure 6 shows the merged TLS and UAV-LS point clouds. It is clearly visible that both methods deliver similar details on stems and branches, but that UAV-LS has a higher coverage towards the top of the canopy, while TLS is stronger lower within the canopy. Stems are well defined in both datasets and larger branches are well resolved as well. Based on our findings and the results of the strip adjustment shown in Section 3.2, we think it is safe to say that it UAV-LS is accurate enough for observing processes having more than 2-3 cm change signal (e.g. landslides or changing riverbeds), while, as other mobile laser-based methods, it is likely not accurate enough for processes with millimeter accuracy requirements, e.g. as subsidence. Occlusion of lower canopy parts is still a problem in summer (leaf-on conditions), where only a limited number of returns can penetrate the canopy and reach the ground beneath the trees (leaf-on data not shown). It appears as if the smaller beam, lower flying altitude and large variation of incidence angles (compared to traditional ALS) only mitigates the occlusion to some extent, i.e. for all ground focused campaigns, leaf-off still remains the survey condition of choice.

6. CONCLUSION

Our aim using UAV for laser scanning was to obtain accurate stem locations and terrain model over areas of several hectares. Considering the results, we have seen that UAV-LS data will be able to provide not only that, but should as well provide stem and larger branch volumes, which is good news for forest ecology and inventory applications. Terrain elevation accuracy is high enough to facilitate monitoring of a large number of environmental processes. A large advantage of the UAV-LS compared to TLS is the more homogenous point distribution and the perspective from above, leading to more accurate canopy height estimations. The physical limits of occlusion, however, can not be outsmarted using UAV-LS, so that flying in leaf-off conditions is still favorable, when DTM or wood volume are target variables. Summarizing, UAV-LS is the ideal tool to bridge the gap between ALS and TLS and it is a unique proposition for many local scale forest canopy and surface elevation related observation tasks.
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