A case study for detection and modelling of submerged deadwood from UAV-borne topo-bathymetric LiDAR point clouds

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1. Introduction

Alluvial forests constitute an important and ecologically sensitive habitat. Diseases of endemic tree species like ashes have increased the amount of dead wood in alluvial forests in Austria in the recent past (Kessler et al. 2012). During seasonal flood peaks, the increased discharge carries deadwood stems into the active river channels, where they are floating downstream until either natural or artificial barriers (river bends, bridge piers, hydropower stations, etc.) stop their movement. On the one side, stranded driftwood plays an important role in aquatic ecosystems, e.g. as shelter for juvenile fish stages, but on the other side, it can cause severe problems like log jams potentially resulting in flooding of residential areas. For these reasons, monitoring of the volume and distribution of driftwood within rivers and lake outlets is an important topic from both an ecologic and socio-economic point of view.

In the recent past, airborne topo-bathymetric LiDAR (Light Detection And Ranging) has gained increased importance for mapping the littoral zone of both coastal and inland water areas. Bathymetric LiDAR uses short laser pulses in the green domain of the electro-magnetic spectrum for measuring objects above and below the water table. One of the main issues in bathymetric LiDAR is eye safety, as the green radiation also penetrates the human eye potentially causing severe injuries. For this reason, a larger beam divergence is used in bathymetric LiDAR resulting in typical footprint diameters in the range of about 50 cm for data acquisition from manned platforms. This, however, hampers the detectability of submerged tree stems and branches, especially for stem diameters < 30 cm. The advent of UAV-borne topo-bathymetric LiDAR sensors has changed this situation fundamentally, as these systems provide small laser footprint diameters of around 10 cm and a high laser pulse density of > 200 points/m^2.

In this case study we present early results of using 3D point clouds acquired with a survey-grade topo-bathymetric laser scanner for detecting and modelling submerged driftwood. We demonstrate that stems and even branches are well recognizable in the point cloud and that the achieved point density and measurement precision allows derivation of the driftwood skeleton parameters like tree length and diameter. This enables quantitative analysis of submerged biomass.

2. Study area and data sets

The flight campaign took place on March 9, 2021 at the Pielach River, a pre-Alpine, right hand tributary of the Danube river in Lower Austria (48° 12’ 50”N, 15° 22’ 30”E) with a lightweight *RIEGL* VQ-840-G topo-bathymetric laser scanning system mounted on an octocopter UAV platform. The sensor operates at pulse repetition rates (PRR) of 50-200 kHz and enables arbitrary choice of the laser beam divergence within a range of 1-6 mrad (Mandlburger et al. 2020). This allows balancing the achievable depth penetration and spatial resolution. The employed sensor provides a maximum depth penetration of 1-2 times the Secchi depth (Effler 1998) and a laser footprint diameter of 5-30 cm for a typical flying altitude of 50 m above ground level (agl) (Mandlburger et al. 2020). To test the detection and modelling of driftwood, a 750 m long section of the meandering river course was captured with 17 short strips (cf. Figure 1) in two separate flights using the flight mission parameters reported in Table 1. Because of

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the green wavelength, the canopy of the alluvial forest, ground below it, and the mid-storey were captured, as well as water surface, riverbed, and reflections in the water column in between.

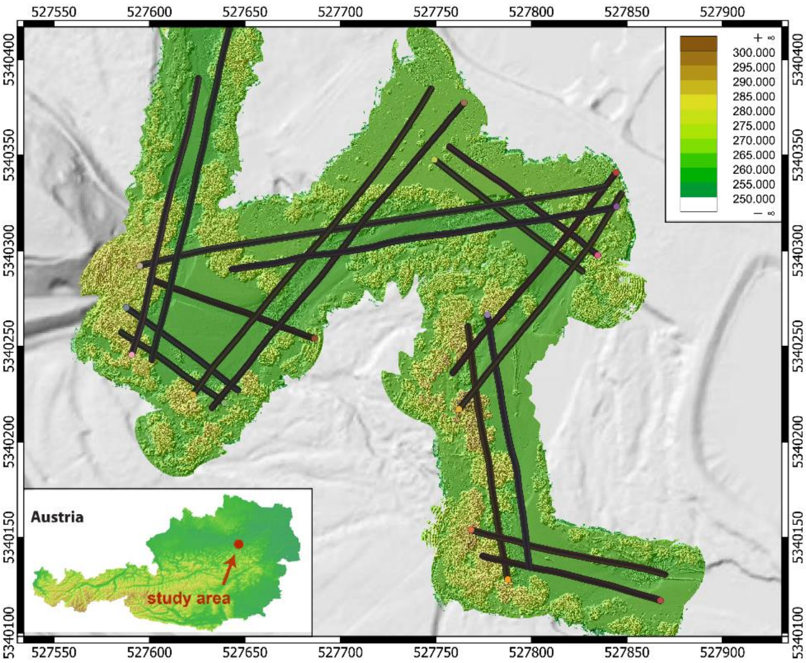

Figure 1: Study area Pielach river: superposition of shaded and color coded DSM map, image background: basemap.at (terrain); UAV flight trajectory (black framed dots), Coordinate Reference System: ETRS89/UTM33 (EPSG:25833); lower left: location of study area within

Table 1. UAV flight mission parameters.

PRR	Flying altitude	Beam divergence	Footprint diameter	Laser pulse density
50 kHz	50 m agl	2 mrad	10 cm	200 points/m^2
200 kHz	60 m agl	1 mrad	6 cm	600 points/m^2

3. Methods

After alignment and georeferencing of the laser strips, a standard quality assessment was performed to evaluate the achieved precision (< 3 cm) and point density (> 200 points/m^2). After modelling the water surface and refraction and run-time correction of the raw laser measurements, a Digital Elevation Model (bare ground + submerged bottom) was derived using hierarchical robust interpolation (Pfeifer and Mandlburger 2018). In a subsequent processing step, the volumetric point density of all submerged points within the water column (i.e., points classified neither as riverbed nor as water surface) was calculated. Points meeting a certain minimum 3D point density were classified as underwater vegetation. Visual analysis revealed that there are two categories of submerged vegetation: (i) single broad tree stems, and (ii) bunches of smaller branches. Especially for the prior, the high point density enabled semi-automatic estimation of stem diameters using the approach of Wieser et al. (2019).

4. Results and discussions

Figure 2 shows 3D point clouds of submerged driftwood in perspective views. Figure 2a exhibits a large individual stem colored by RGB and Figure 2b features many thin branches of an entire willow tree colored by class ID (red=submerged vegetation). While the trunk of the larger stem in Figure 2a is already buried into the riverbed gravel, the small willow tree just recently broke off the steep bank side and is not anchored in the ground. Both examples prove the feasibility of (i) detecting and (ii) automatically classifying underwater vegetation from UAV-borne topo-bathymetric point clouds. For the

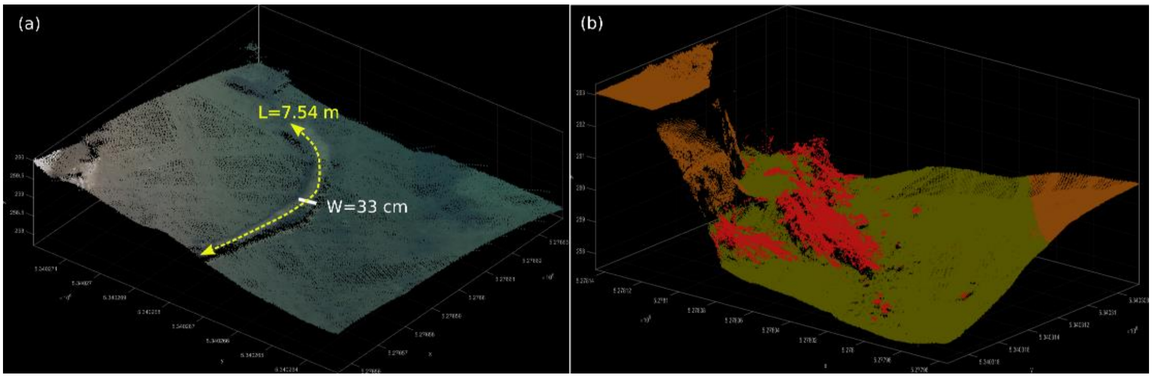

Figure 2: Examples of 3D point clouds of submerged driftwood. (a) single stem (colored by RGB); (b) bunch of willow tree branches (colored by class ID; red=submerged driftwood)

larger stem, semi-automatic width estimation resulted in a stem diameter of 33 cm. In addition, a length of 7.54 m was derived via manual digitization in a 3D viewer. In contrast to deadwood detection in dry forests (Mücke et al. 2013, Lindberg et al. 2013), submerged driftwood is often sparser and the absence of understorey facilitates detection. On the other hand, forward scattering of the laser signal underwater leads to blurring of the points clouds, which complicates (i) automatic detection of dense small structures (branches) and (ii) precise estimation of stem widths due to progressive broadening of submerged driftwood point clouds with increasing water depth.

5. Conclusions and outlook

In this study, we demonstrated that UAV-borne topo-bathymetric LiDAR is a suitable tool for detecting submerged driftwood. The automatically classified 3D points enabled the quantification of relevant stem parameters like length and width via either semi-automatic analysis or manual digitization. With these promising early results, ongoing research focuses on (i) improving the classification of driftwood, (ii) automatic segmentation of individual stems, and (iii) further automation of parameter retrieval, and (iv) accuracy assessment of the derived metrics w.r.t. reference data with special emphasis on unbiased stem width estimation.

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