Close-Range Remote Sensing for National Forest Inventory Applications – A Comparison of Terrestrial and Airborne Approaches

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1. Introduction

Evaluation of the state and dynamics of forest ecosystems requires accurate, repeated and robust measurements of important forest biophysical parameters. Such measurements and forest assessments are traditionally performed within the framework of National Forest Inventories (NFI), where established field measurement methodologies are often time-consuming and sometimes subject to observer bias. New methodologies for accurate and quantitative, wall-to-wall acquisitions of different forest parameters could potentially advance the way NFIs are performed. With the recent developments in the field of terrestrial, mobile and drone-based laser scanning (TLS, MLS, UAVLS) as well as new advances in terrestrial and aerial structure from motion (SfM) applications, close-range remote sensing could play an important role in supporting traditional NFIs. However, in order to include these technologies within the framework of an operational NFI, its robustness and applicability needs to be assessed and evaluated.

In this contribution, we evaluate multiple close-range remote sensing technologies for the potential to support NFIs. We evaluate the performance to extract important forest inventory parameters such as tree position and diameter at breast height (DBH) and analyse the coverage and completeness of acquired datasets in respect to three 50x50 m^2 plots within a Swiss temperate mixed forest.

2. Data and Methods

The study area is located in a temperate mixed forest close to Zurich, Switzerland. For a 1 ha large plot, tree positions and DBH of all trees with a DBH >= 7 cm as well as a TLS campaign under leaf-off conditions using a FARO Focus3D scanner were acquired. Within the 1 ha plot, three 50x50 m^2 plots were defined, following the plot size definition of the Swiss NFI. These three plots were used to test multiple sensors with varying characteristics and acquisition patterns. The three plots showed varying tree densities (340, 440, and 564 trees/ha with DBH >=7cm) with varying species compositions and structural complexity (e.g. dense understorey vegetation). A set of TLS, MLS, UAVLS sensors as well as a terrestrial structure from motion (SfM) image acquisition was tested on these three plots, which are summarized in Table 1. All datasets were analysed regarding their point density distribution within the canopy, the coverage of the 50x50 m^2 plots and the extraction of the digital terrain model, where the DTM derived from the FARO TLS scan served as the reference. Tree positions and DBH were also extracted from all datasets and compared to reference acquisitions using a tachymeter and a calliper. We restricted the tree position and DBH comparison to trees with DBH >=12 cm, following the methodology of the Swiss NFI. Tree positions and DBH were extracted using the R-package TreeLS (De Conto et al. 2017). Tree detection and DBH extraction performance was evaluated regarding their correctness (fraction of matched trees to number of detected trees), completeness (fraction of matched trees to number of reference trees), and the BIAS and RMSE of the DBH extraction. A detected tree was labelled as matched if a reference tree was found within 2 m from the detected position and the estimated DBH did not deviate more than 20% from the reference.

3. Results and Discussion

The analysed 3D point-cloud datasets differ substantially in terms of point density as well as point density distribution (Table 2 and Figure 1). Table 2 summarises the results from the dataset comparison.

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Table 1: Acquired dataset specifications. Acquisition times refer to the 50x50 m^2 interpretation area unless otherwise stated (i.e. UAVLS and FARO acquisitions). Approximate distance between scan positions for TLS acquisition are specified with Δd.

Sensor	Sensor Type	Acquisition Date	Acquisition Pattern	Acquisition Time
FARO Focus3D	Phase Shift TLS	January 2020 (Leaf-Off)	Regular grid $\Delta d \approx 10$ m	6 days (for 1 ha)
Leica BLK 360	Time of flight TLS	September 2020 (Leaf-On)	Regular grid $\Delta d \approx 5$ m	6 hours
Riegl VUX1-UAV	UAVLS	March 2020 (Leaf-Off)	Regular grid	≈2 hours (for 52 ha)
Riegl miniVUX2	UAVLS	September 2020 (Leaf-On)	Regular grid	20 minutes (for 1 ha)
ZebRevo	MLS	October 2020 (Leaf-On)	Snake pattern	≈20 minutes
GoPro Hero 8 Black (12MP)	Terrestrial SfM	September 2020 (Leaf-On)	Circular Pattern	≈20 minutes

The average over all three plots is given, however the DTM accuracy as well as the tree detection and DBH extraction performance is highly dependent on the structural complexity of the plots. The two denser plots show multiple patches of very dense undergrowth, making data acquisition and the extraction of terrain and tree parameters in these areas difficult. Compared to the reference datasets, the leaf-on acquired BLK360 TLS acquisition performed best. However, the faster acquired and processed ZebRevo point-cloud performs similarly as the BLK360, even with the lower precision of the instrument. However, some trees were missed by the ZebRevo. The GoPro camera was able to detect more than 50% of the reference trees, however, it also only covered in average 80% of the entire plot area. Nevertheless, the estimated DBH of the detected trees show quite accurate results, even outperforming those extracted from the BLK360 acquisitions. However, further investigations are needed to fully evaluate the performance of each approach. The quality of extracted point-clouds from SfM acquisitions is highly dependent on the acquisition pattern, structural complexity (undergrowth vegetation) as well as the conditions during the acquisitions (light, wind). Further investigations are needed to analyse the robustness of such acquisitions for the use within NFIs.

UAVLS acquisitions, especially under leaf-on conditions (miniVUX2), showed some difficulties in accurately extracting terrain and tree information. The often dense overstorey vegetation resulted in substantially occluded areas in the lower canopy regions as also depicted in Figure 1. Further analysis on best acquisition patterns (e.g. Bruggisser et al., 2020) to acquire data or the possibilities to use within canopy UAVLS flights (e.g. Hyyppä et al., 2020) could possibly help in this regard.

Table 2: Summary of extracted point-cloud acquisitions and the performance for DTM extraction and tree detection and DBH extraction from the different point-clouds. The average over all three analysed plots is given for all metrics.

Sensor	Point Density [pts/m^2]	DTM Coverage [%], Mean [m], std [m]	Tree detection [Correctness, Completeness]	DBH Difference Bias, RMSE [cm]
FARO	869’862	Reference	0.91/0.83	0.13/2.42
BLK 360	1’203’548	100/0.03/0.11	0.76/0.77	1.45/4.43
VUX1-UAV	4’372	100/-0.12/0.12	0.75/0.43	1.67/3.7
miniVUX2	1’888	100/0.18/0.92	0.44/0.14	-2.94/4.45
ZebRevo	15’777	100/-0.06/0.13	0.73/0.59	0.5/3.92
GoPro8	29’523	80.3/0.3/1.5	0.87/0.51	0.5/2.59

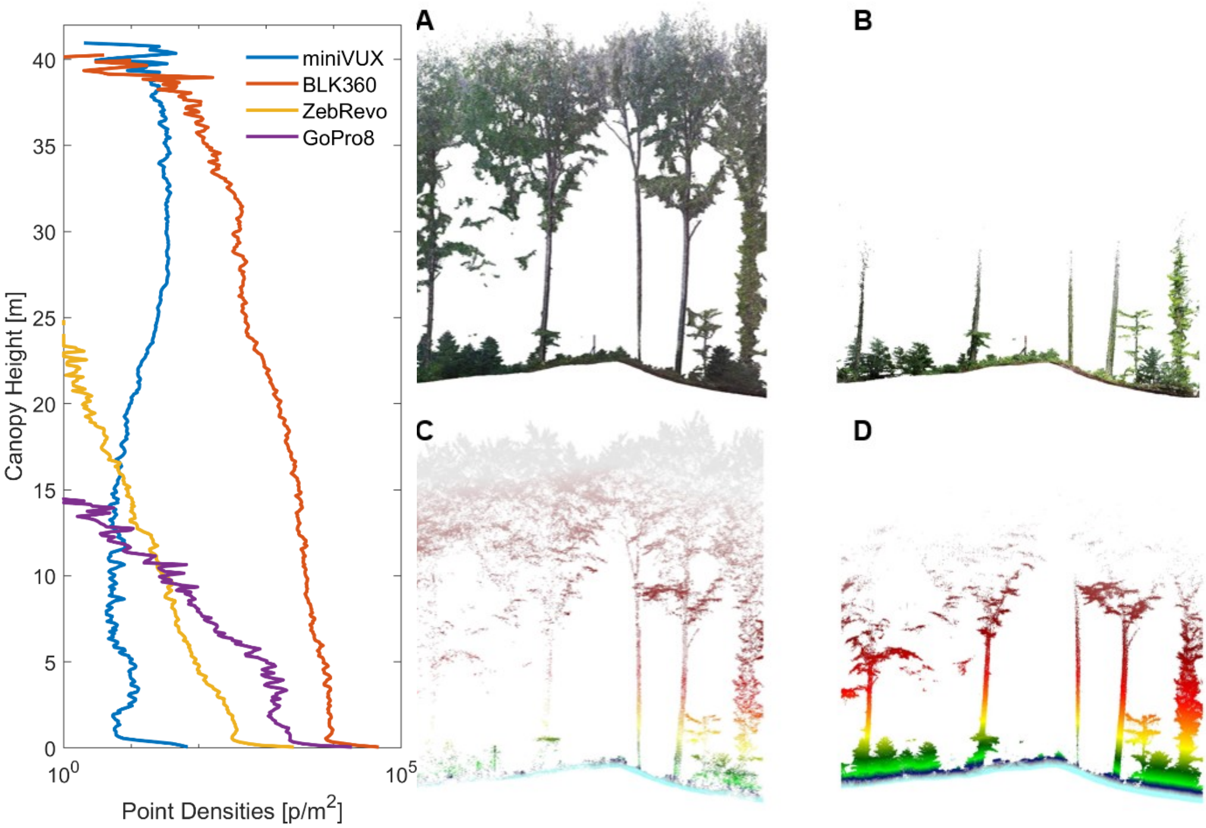

Figure 1: Vertical point density distribution and transects through point-clouds for BLK360 (A), GoPro 8 (B), miniVUX2 (C) and ZebRevo (D) acquisitions.BLK360 and GoPro point-clouds colored based on RGB camera information, miniVUX2 and ZebRevo point-clouds colored according to height above ground.

4. Conclusions

Close range remote sensing technologies are increasingly investigated regarding their potential for an operational application within NFIs. TLS reign as the high standard for acquiring high detailed 3D information at the single tree level. However, long and complicated acquisition procedures often neglect an operational inclusion within NFIs. Technologies allowing for faster data acquisition, however often at the price of a loss in precision and accuracy, such as MLS, UAVLS or even terrestrial or UAV SfM, therefore become increasingly more popular. In this study we analysed multiple sensor and acquisition approaches to extract terrain and tree information in three plots of varying complexity. Further analysis is needed to analyse the robustness of each approach in terms of applicability within a national forest inventory. Nevertheless, close range remote sensing shows high potential for forest structure assessment within the framework of a NFI.

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