Forest Inventory with Apple iPad Pro and integrated LiDAR Technology

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1. Introduction

The estimation of stand- and individual tree information is one of the major goals of forest inventory. Conventionally, field data in forest inventory are collected at tree level on sample plots by means of manual measurements (e.g., caliper, tape). This is labor-intensive, time-consuming and prone to manifold measurement errors (Liang et al. 2016, 2018; Ritter et al. 2017). In recent years, modern laser-supported sensors and automatic routines for feature extraction were increasingly used instead of the traditional forest inventory methods. Nevertheless, most forest inventories still rely on manually collected tree information. The rationale is the sometimes time-consuming and incomplete data acquisition and the high purchase costs for terrestrial and personal laser scanners (TLS/PLS). In 2020, Apple (Apple Inc. Cupertino, California, USA) implemented a LiDAR (Light Detection and Ranging) sensor in the new 4th Generation of Apple iPad Pro. Consequently, LiDAR-generated 3D point clouds can nowadays be recorded with consumer-level devices for the first time.

The goal of the present study was to assess the accuracy of forest inventory variable estimates obtained by Apple iPad Pro under various stand and terrain conditions. The results of the iPad data were compared with PLS results on the same forest inventory plots, using the same algorithms for automatic tree detection and dbh modelling. Manual measurements on the sample plots served as reference data.

2. Data and Methods

A sample of 21 forest inventory plots was scanned in December 2020 using an iPad and a GeoSLAM ZEB Horizon (GeoSLAM Ltd. Nottingham, UK) PLS. The plots were selected in such a way that a broad variation in forest type (broadleaved, coniferous, and mixed), forest structure (one- or two-layered), and terrain property (flat to steep) was represented. On the iPad, multiple scanning apps were evaluated in a forest environment during a preliminary testing before settling on 3D Scanner App (https://www.3dscannerapp.com/) (Laan Labs, New York, US), Polycam (https://poly.cam/) (Polycam Inc., San Francisco, US) and SiteScape (https://www.sitescape.ai/) (SiteScape Inc., Waltham, US). Data acquisition with iPad and PLS started in the sample plot center. The sample plot radius was set to 7 m with a 0.5-1 m buffer zone for the scan survey. The recording of the entire sample plots consumed approximately 5–10 minutes for iPad and 3-7 minutes for PLS, depending on the possible walking speed. Using iPad, every individual tree was circled on the sample plot, while with PLS, only the whole sample plot was circumvented and crossed once. Screen shots from scanning with the iPad with all three apps can be found in Figure 1.

Following the field data collection, further point cloud processing and analysis was performed using statistical computing language R with the algorithms for tree detection and dbh estimation, presented in Gollob et al. (2020). The diameter modelling was carried out with five different approaches (2 GAMs, 2 circles, 1 ellipse), whereby these diameters were referred to as d_{gam}, d_{tegam}, d_{circ}, d_{circ2} and d_{ell}. The accuracy of tree detection was evaluated in terms of two measures: detection rate $d_r(\%)$ and commission error $c(\%)$. The accuracy and precision of dbh estimation were assessed by means of root mean square error (RMSE) and bias.

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(a) (b) (c)

Figure 1: iPad data acquisition with (a) 3D Scanner App, (b) Polycam and (c) SiteScape.

3. Results and Discussion

The analysis of the 21 sample plots showed that the detection rate d_r(%) strongly depended on the lower dbh threshold (Table 1). Furthermore, iPad scans (3D Scanner App, Polycam and SiteScape) generally had lower detection rates than PLS scans. The average detection rates for 3D Scanner App, Polycam and SiteScape over all 21 sample plots and dbh thresholds ranged from 84.49% to 98.06%, from 76.67% to 94.68% and from 81.41% to 97.26%, respectively. The corresponding average detection rates for PLS ranged from 98.10% to 100%. The commission error c(%) increased slightly with increasing lower dbh threshold. In general, the average of the commission errors was smaller with all iPad apps than with PLS. Commission errors were below 4% across all technologies and thresholds.

Table 1. Detection rates and commission errors for PLS/iPad and lower dbh thresholds.

	Detection Rate d_r (%)				Commission Error c (%)			
dbh	**PLS**	**3D Scanner App**	**Polycam**	**SiteScape**	**PLS**	**3D Scanner App**	**Polycam**	**SiteScape**
≥5 cm	98.10	84.49	76.67	81.41	2.11	2.47	0.53	1.35
≥10 cm	99.52	97.33	90.65	95.06	2.58	2.55	0.60	1.40
≥15 cm	100.00	98.06	94.68	97.26	3.10	2.80	0.68	1.87

The performance of automatic dbh estimation for iPad and PLS is outlined in Table 2. The average RMSE for 3D Scanner App, Polycam and SiteScape over all 21 sample plots, dbh thresholds and fitting methods ranged from 3.10 cm to 3.40 cm, from 3.05 cm to 4.70 cm and from 3.18 cm to 3.48 cm, respectively. The corresponding average RMSE for PLS ranged from 1.50 cm to 1.92 cm. The average bias for 3D Scanner App, Polycam and SiteScape over all 21 sample plots, dbh thresholds and fitting methods ranged from -1.56 cm to -0.39 cm, from -0.92 cm to 0.58 cm and from -1.38 cm to -0.83 cm, respectively. The corresponding average bias for PLS ranged from -1.32 cm to -0.04 cm.

Table 2. RMSE and bias of dbh estimation for PLS/iPad and lower dbh thresholds.

dbh	method	RMSE (cm) PLS	RMSE (cm) 3D Scanner App	RMSE (cm) Polycam	RMSE (cm) Site-Scape	bias (cm) PLS	bias (cm) 3D Scanner App	bias (cm) Polycam	bias (cm) Site-Scape
≥5 cm	gam	1.85	3.12	4.08	3.20	-0.51	-1.01	0.39	-1.31
	tegam	1.78	3.10	4.70	3.18	-0.21	-1.06	0.58	-1.20
	circ	1.64	3.11	3.85	3.39	-0.73	-0.39	0.44	-0.90
	circ2	1.73	3.19	4.05	3.21	-0.54	-1.04	0.36	-1.17
	ell	1.92	3.11	4.20	3.20	-0.04	-1.03	0.28	-1.03
≥10 cm	gam	1.65	3.18	3.84	3.20	-1.05	-1.17	0.08	-1.28
	tegam	1.50	3.17	3.80	3.21	-0.73	-1.18	0.04	-1.17
	circ	1.65	3.18	3.55	3.41	-1.13	-0.52	0.12	-0.83
	circ2	1.64	3.24	3.80	3.22	-1.01	-1.20	0.05	-1.16
	ell	1.52	3.18	3.96	3.20	-0.66	-1.15	0.01	-1.03
≥15 cm	gam	1.78	3.38	3.09	3.26	-1.28	-1.52	-0.87	-1.38
	tegam	1.56	3.36	3.14	3.28	-1.00	-1.52	-0.83	-1.28
	circ	1.77	3.37	2.88	3.48	-1.32	-0.79	-0.80	-0.89
	circ2	1.77	3.40	3.05	3.28	-1.24	-1.56	-0.90	-1.26
	ell	1.60	3.36	3.29	3.21	-0.98	-1.46	-0.92	-1.08

One of the major advantages of applying mobile or personal laserscanning systems is rapid data acquisition on forest sample plots. Although the development of LiDAR devices is proceeding rapidly, it can be stated that the relatively high price of the devices often hinders a wider application at the level of forest practitioners. The PLS (GeoSLAM ZEB HORIZON) used in this study costs around € 50,000. Apple iPad pro costs around € 1,000 and thus easily provides access to LiDAR technology. While the used PLS with a maximum range of 100 m is well suited for capturing upper diameters, tree heights or canopy shapes, iPad measures the distance to surrounding objects only up to 5 meters. Thus, a disadvantage of the iPad method is that it is not capable of acquiring upper tree parameters. However, the technology of these consumer-level devices will also develop further quickly, which means that significantly higher ranges could then be achieved.

3. Conclusion

The LiDAR Sensor of the new iPad is capable for efficient data collection. A large proportion of the trees could be automatically detected, and dbh estimates showed sufficient accuracy, even with existing algorithms. With a further development of hardware and software, the iPad or similar consumer-level devices could provide a feasible, sufficiently accurate, and cost-effective solution for various measurements in near future. This would also mean another important step towards the practical use of digital forest inventory.

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