# Testing the performance of the-state-of the-art hand-held personal laser scanning systems for tree height estimations in lowland pedunculate oak forests

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## 1 RESEARCH AIMS

- test the performance of two, high-end handheld personal laser scanning (PLS) systems for tree height estimation in a lowland pedunculate oak (*Quercus robur* L.) forest
- compare PLS estimates with conventional field measurements

## 2 STUDY AREA

- 100-years-old, mixed, lowland, even-aged pedunculate oak forest stand (*Carpino betuli - Quercetum roboris*) located in Central Croatia (MU "Bolčanski-Žabljački lug") (Fig. 1)
- **three circular sample plots** (r=12,62 m) chosen from a set of 13 systematically distributed plots (Fig. 1) representing low-, medium-, and high-density sample plots, respectively (Fig. 2)

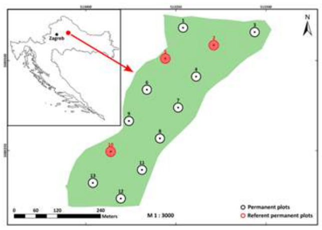


**Fig. 1.** Study area.

Low-density (N=15)

Medium-density (N=21)

High-density (N=29)

**Fig. 2.** Panoramic views of 3 circular sample plot.

## 3 DATA COLLECTION AND PROCESSING

- **during the leaf-off conditions** (January – February 2024)
- the heghts (h) off all trees with dbh≥5 cm were measured or estimated using conventional field method (Vertex III), static terrestrial laser scanner (TLS) and PLS instruments (Fig. 3)

**Fig. 3.** Tree height data collection.

### Terrestrial laser scanning (TLS)

- Faro FOCUS Premium 150 (Fig. 3, middle)
- multi-scan approach, 9 scan positions (Fig. 4)
- scan resolution: 1/2; quality 2×; scan time ≈ 6 min
- processing: Faro Scene, LiDAR360
- three heights manually estimated (LiDAR360)
- **ground-truth reference data**

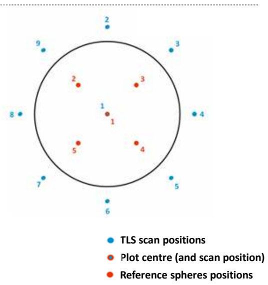


**Fig. 4.** Scheme of TLS data collection

### Personal laser scanning (PLS)

- PLS systems: Zeb Horizon and Faro Orbis (Fig. 5, Tab. 1)
- different scanning schemes
- processing: Faro Connect, LiDAR360
- three heights manually estimated (LiDAR360)

**Fig. 5.** Zeb Horizon (left) and Faro Orbis (right)

**Tab. 1.** Technical specifications of Zeb Horizon and Faro Orbis.

| Feature | Zeb Horizon | Faro Orbis |
|---|---|---|
| **Released** | 2019 | 2023 |
| **Range** (m) | 100 | 120 |
| **Acquistion rate** (points/sec) | 300,000 | 640,000 |
| **Field of view** (H/V; °) | 270/360 | 290/360 |
| **Precision** (mm) | up to 6 | 5 (mobile) / 2 (static) |

## 3 DATA COLLECTION AND PROCESSING - continuation

### Personal laser scanning (PLS) - continuation

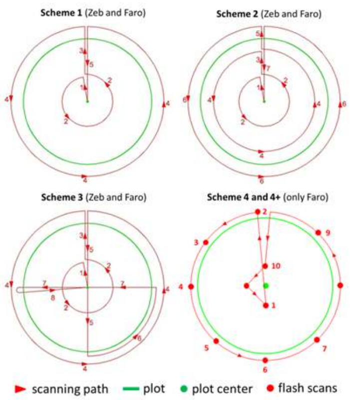


**Fig. 6.** Pre-planned PLS scanning schemes

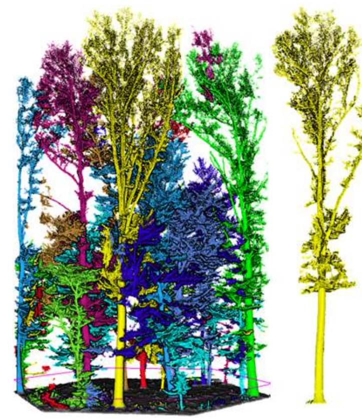

**Fig. 7.** PLS segmented 3D point cloud (plot 10. left) and example of one segmented *Q. robur* tree

## 4 RESULTS

**Tab. 2.** Estimation accuracy of tree heights for two PLS instruments (Zeb Horizon, Faro Orbis), and different scanning schemes in comparison to ground-truth reference TLS data.

| | Vertex | Zeb Horizon | | | Faro Orbis | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Scheme** | | 1 | 2 | 3 | 1 | 2 | 3 | 4* | 4+** |
| **Min** (m) | -3.08 | -0.95 | -0.95 | -0.99 | -1.08 | -1.07 | -1.06 | -1.05 | -1.10 |
| **Max** (m) | 7.52 | 0.56 | 0.59 | 0.55 | 0.49 | 0.58 | 0.53 | 0.54 | 0.48 |
| **ME** (m) | 0.43 | -0.01 | 0.02 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | -0. 02 |
| **ME** (%) | **1.95** | **-0.06** | **0.07** | **0.03** | **0.08** | **0.14** | **0.10** | **0.08** | **-0.11** |
| **RMSE** (m) | 1.73 | 0.24 | 0.21 | 0.22 | 0.20 | 0.21 | 0.22 | 0.22 | 0.22 |
| **RMSE** (%) | **7.79** | **1.07** | **0.93** | **0.97** | **0.89** | **0.93** | **1.00** | **1.01** | **0.99** |

**4*** Faro Orbis, only flash scans; **4+**** Faro Orbis – combination of flash and mobile scan
ME – mean error, RMSE – root mean square error

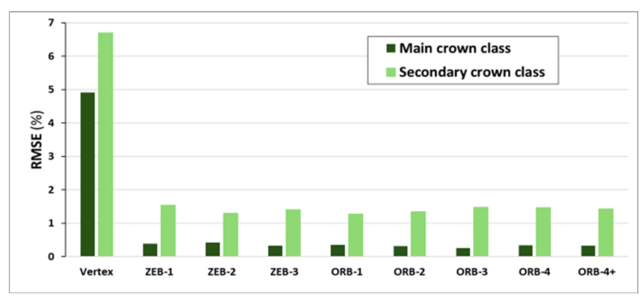


**Fig. 7.** RMSE% values of PLS tree hight estimates observed by crown classes (**Main crown class** – dominant and co-dominant tree layer, e.g., *Quercus robur* L.; **Secondary crown class** – intermediate and suppresed tree layer, e.g., *Carpinus betulus* L., *Ulmus laevis* Pall., etc.)

## 5 CONCLUSIONS

- our previous research (Kokeza et al. 2024, https://doi.org/10.5281/zenodo.1165) showed that type of instrument and complexity of applied scanning scheme influence on the accuracy of PLS diameter at breast height estimates
- unlike that, this research showed that both instruments and regardless of the applied scanning scheme provide tree height estimates of very similar accuracy
- compared to ground-truth reference TLS data, PLS provides tree height estimates of considerably higher accuracy than conventional field method (Vertex III hypsometer)
- furthermore, PLS provides more accurate height estimates for trees from main crown class than for trees from secondary crown class (leaning trees, intertwined treetops, etc..)



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