Modelling and estimating height of lowland oak forests using various 3D remote sensing data

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1 BACKGROUND AND PURPOSE

- Tree height (h) is one of the fundamental measurements in forest inventories.
- In combination with diameter at breast height (dbh) it is used to calculate and estimate various tree-, plot- and stand-level attributes (e.g. volume, biomass, carbon stock, etc.), as well as to estimate the growth and productivity of forest stands, and site quality (index).
- In addition to classical (time-consuming and labor-intensive) field measurements, Remote Sensing (RS) methods can be used to measure thee heights for individual trees or to estimate the mean values at the plot/stand level. RS methods can reduce field work and improve the efficiency, but the accuracy of obtained results have to be carefully tested and evaluated.
- **The main goal of this study** is to test the aplicability of various RS data for estimation of plot-level tree heights:
  - ✓ Lorey's mean height (H_L),
  - ✓ Dominant tree height (H_D).

2 STUDY AREA

- Lowland forest complex of Pokupsko Basin, 35 km SW of Zagreb, Central Croatia (**Fig. 1**);
- Even-aged pedunculate oak (*Quercus robur* L.) forests (**Fig. 2**) characterized with flat terrain (105-118 m a.s.l.);

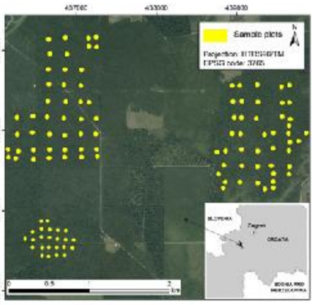


Figure 1. Study area.

Figure 2. 83-year-old pedunculate oak stand.

3 FIELD REFERENCE DATA

Table 1. Summary of the main forest attributes for the 83 measured sample plots (r=8 or 15 m).

Forest attribute	Range	Mean	SD
Age (years)	43 – 93	63	15.8
Mean DBH (cm)	17.0 – 39.9	26.4	5.8
Stem density (trees·ha^{-1})	311 – 1840	653	327
Lorey's mean height (m)	18.2 – 30.0	24.2	2.9
Dominant height (m)	20.4 – 32.5	26.4	3.2

- Field data were collected during 2017 on the systematic sample of 83 circular plots;
- RTK GNSS measurements s of plot centers;
- **dbh** was measured for all trees with dbh≥10 cm; **h** was measured for at least 50% of trees per plot; h of other trees in the plots estimated using the constructed height curves;
- H_L of each plot was calculated by multiplying the tree height by its basal area and then dividing the sum of this calculation by the total basal area of a plot;
- H_D was calculated as the average height of the thickest 20% of trees in the plot.

4 REMOTE SENSING DATA

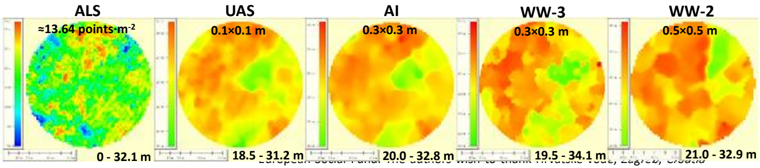
- **Airborne Laser Scanning (ALS)** – summer 2016; the acquisition and processing were done by Institute for Photogrammetry (Zagreb, Croatia) and Mensuras Ltd. (Maribor, Slovenia); Optech ALTM Gemini 167 laser scanner; point density of ≈13.64 points·m^{-2}.
- **Unmanned Aerial System images (UAS)** – May 2017; fixed-wingTrimble UX5 HP; Sony Alpha 7R camera; flying height ≈600 m above ground level; 1441 RGB images with overlap of 90% and 80%; GSD≈0.08 m; image orientation using PPK dual-frequency GNSS data supported with 10 GCPs.
- **Aerial images (AI)** – summer 2015; from national topographic survey; UltraCamXp; RGB images; overlap of 60% and 30%; GSD≈0.08 m; orientation using interior and exterior orientation parameters.
- **WorldView-3 stereo images (WV-3)** – June 2017; Ortho-Ready Standard (ORS2-A); panchromatic images with GSD=0.31 m, multispectral images with GSD=1.24 m; applied pansharpening; orientation additionally improved with 6 GCPs collected from official Croatian orthophoto and ALS DTM.
- **WorldView-2 stereo images (WV-2)** – June 2017; Ortho-Ready Standard (ORS2-A); panchromatic images with GSD=0.5 m; orientation additionally improved with 6 GCPs collected from official Croatian orthophoto and ALS DTM.

5 METHODS

a) **Photogrammetric processing** – PHOTOMOD 6.3 software; included image orientation, pansharpening of WV-3 images, and generation of Digital Surface Models (DSMs) using Dense DSM algorithm (Semi-Global Matching method); DSMs were generated with originating images' spatial resolution (GSD).

b) **Extraction of plot-level point cloud (PC) and DSMs' metrics** – FUSION LDV 3.80; ALS point cloud and images' DSMs were normalized using ALS DTM (Fig. 3); Metrics were extracted for each plot using the min height threshold of 1 m to remove ground and understorey vegetation, the height thresholds of 5, 10, 15, 20, and 25 m was applied to calculate the canopy cover metrics; An extracted metrics were grouped into: height metrics, height variability metrics, height percentiles, and canopy cover metrics.

c) **Development and validation of plot-level H_L and H_D models** – STATISTICA 11 software, MATLAB R2018a and MATLAB RSR toolbox; A large number of potential independent variables were reduced based on strength of correlation with dependent variables (r<±0.5) and collinearity analyses (r≥±0.7); Remaining variables entered the multivariate linear regression (backward stepwise approach); The-best-fit H_L and H_D models were selected for each RS dataset and validated using the leave-one-out cross-validation (LOOCV).



European Social Fund. The authors wish to thank Hrvatske vode, Zagreb, Croatia
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Figure 3. Normalized ALS point cloud and images' DSMs for one examplary sample plot.

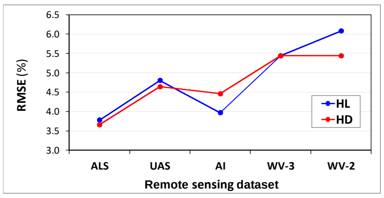
6 RESULTS

Table 2. Selected plot-level H_L and H_D models and results of leave-one-out cross-validation (LOOCV).

R^2_{ADJ} - adjusted coeficient of determination; **RMSE** - root mean square error; **ME** - mean error; **P75** - 75th percentile; **P80** - 80th percentile; **P90** - 90th percentile; **h_{max}** - maximum height; **CC25** - percentage of pixels above 25 m

Attribute	RS data	Model	R^2_{ADJ}	RMSE (m)	RMSE (%)	ME (m)	ME (%)
H_L	**ALS**	$H_L = 2.09 + 0.89 \cdot \mathbf{P90}$	0.90	0.92	**3.78**	0.09	0.38
	UAS	$H_L = 3.85 + 0.79 \cdot \mathbf{P90} + 0.02 \cdot \mathbf{CC25}$	0.84	1.16	**4.80**	0.01	0.03
	AI	$H_L = 3.98 + 0.85 \cdot \mathbf{P75}$	0.89	0.95	**3.97**	-0.02	-0.09
	WV-3	$H_L = 3.27 + 0.86 \cdot \mathbf{P80}$	0.79	1.31	**5.44**	0.22	0.91
	WV-2	$H_L = 9.87 + 0.50 \cdot \mathbf{h_{max}} + 0.02 \cdot \mathbf{CC25}$	0.73	1.47	**6.08**	0.19	0.81
H_D	**ALS**	$H_D = -0.45 + 1.07 \cdot \mathbf{P90}$	0.91	0.97	**3.66**	0.08	0.30
	UAS	$H_D = 4.32 + 0.85 \cdot \mathbf{P90} + 0.02 \cdot \mathbf{CC25}$	0.85	1.23	**4.64**	-0.03	-0.30
	AI	$H_D = 4.40 + 1.01 \cdot \mathbf{P75} - 0.07 \cdot \mathbf{h_{max}}$	0.86	1.17	**4.46**	2.02	7.68
	WV-3	$H_D = 3.23 + 0.95 \cdot \mathbf{P80}$	0.79	1.43	**5.44**	0.19	0.74
	WV-2	$H_D = 4.90 + 0.85 \cdot \mathbf{P90}$	0.79	1.44	**5.44**	0.04	0.15

Figure 4. RMSE (%) values for H_L and H_D models.



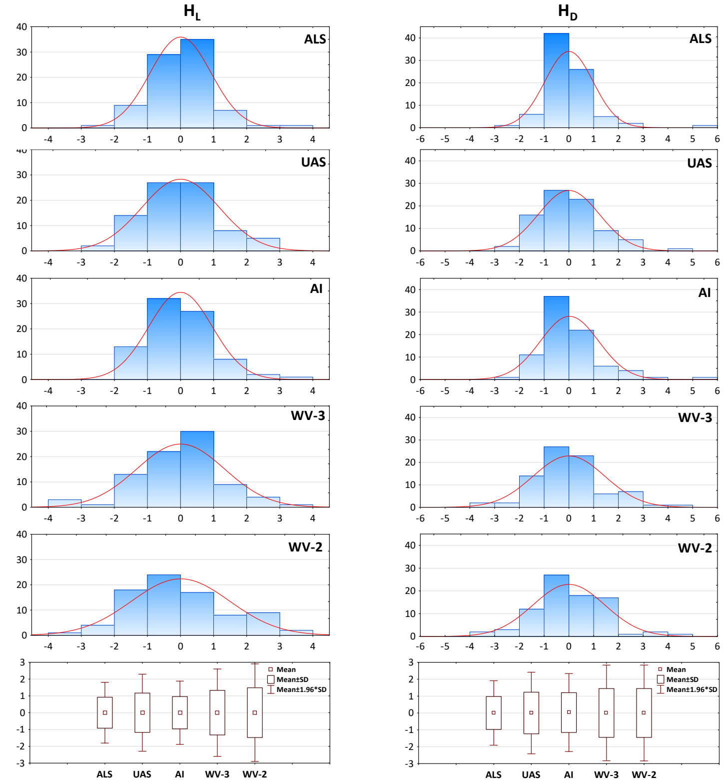


Figure 5. Histograms and Box & Wisker plots of differences between observed (field reference data) and predicted (models estimated) data for HL (left side) and HD (right).

7 CONCLUSIONS

- ➢ This research confirmed the great potential of high-spatial resolution remote sensing data in forest inventory.
- ➢ For all remote sensing datasets, the higher accuracy was obtained for H_D than for H_L.
- ➢ As expected, ALS provided the highest accuracy. The closest to ALS accuracy, for both H_L and H_D, was achieved with AI, followed by UAS, WV-3, and WV-2.
- ➢ A somewhat surprising are the results of slightly higher accuracy obtained for AI than for UAS. However, this could be addressed to the relatively high flying height within the UAS survey, but can not be confirmed due to lack of comparison studies.

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