1. CONTACT INFO

Project title: Application of PHOTOMOD Lite in estimation of forest stands' structure elements

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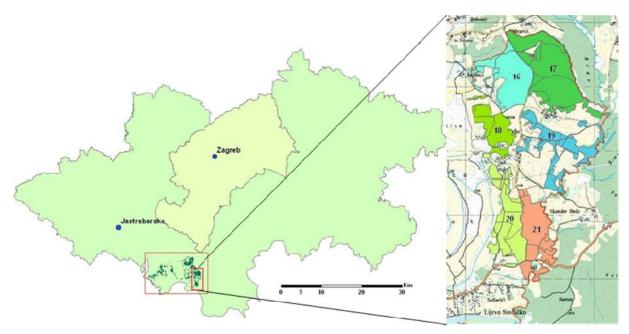**Contact person**: Ivan Balenović, e-mail: ivanb@sumins.hr

2. PROJECT DESCRIPTION

Summary

The diameter at breast height (DBH) is the most important measurement element in forest inventory and provides the basis for many other computations (e.g. basal area, volume). Therefore, the main goal of this project was to investigate the possibility of applying the manual method of digital photogrammetry for DBH estimation at stand (subcompartment) level. The method included the use of digital aerial images of ground sample distance (GSD) of 30 cm and 10 cm, a digital elevation model (DEM), as well as a digital photogrammetric workstation (DPW) with the PHOTOMOD Lite and Global Mapper software.

The research was carried out on the selected part of ''Donja Kupčina - Pisarovina'' forest management unit which covers the total area of 480 ha (Figure 1). The main tree species of the research area are: Sessile oak, Common beech, Common hornbeam and Black alder.

The following was performed: (1) terrestrial measurement of DBHs; (2) the so-called "high" and "low" aerial surveys that captured colour infrared (CIR) digital aerial images of 30 cm and 10 cm GSD; and (3) photogrammetric measurement of tree heights and crown areas in the stereomodels of CIR digital images using DPW. In order to determine whether the applied photogrammetric method is applicable in operational forest inventory, the results obtained by classical terrestrial measurement and photogrammetric measurement were mutually compared.

Figure 1. Left: The location of the ''Donja Kupčina - Pisarovina'' management unit in the Zagreb County. Right: The selected research area.
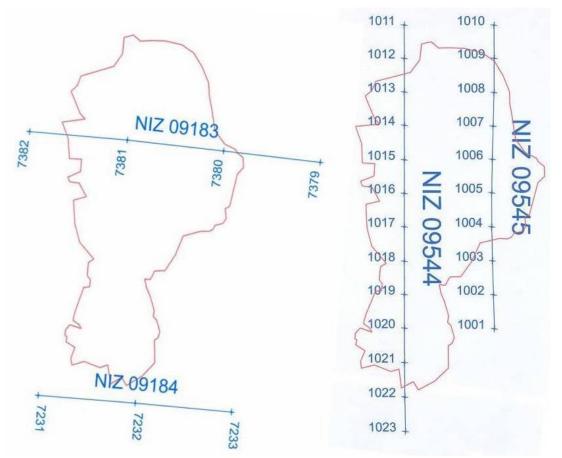
Input data description

Aerial surveys

Two aerial surveys of the research area were conducted by Vexcel UltraCamX digital aerophotogrammetric camera in July 2009. The focal distance of camera lenses was 100.5 mm, while the radiometric resolution was 12 bit. The forward overlap (endlap) of images was 60%, while the lateral (sidelap) was 30%.

1) The so-called "high" aerial survey was done at the flying height of about 4400 m above ground and with the approximate scale of 1:5000. Along two flight lines, 10 CIR digital aerial images of GSD 30 cm were acquired (Figure 2, left).
2) The "low" aerial survey was done at the flying height of about 1400 m above ground and with the approximate scale of 1:1000, the product of which were 23 CIR digital aerial images of GSD 10 cm, acquired along two flight lines (Figure 2, right).

The aerial surveys of the research area and the post-processing of acquired digital aerial images were performed by Geofoto Ltd, Zagreb.

Figure 2. Schematic view of conducted aerial surveys: left - 'high' aerial survey, right - 'low' aerial survey. The red line denotes border of the research area. Blue lines show flight lines along which digital aerial images are acquired. Each acquired images are presented with number.
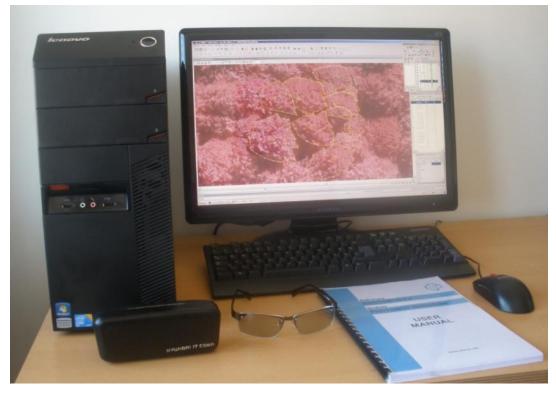
Hardware profile
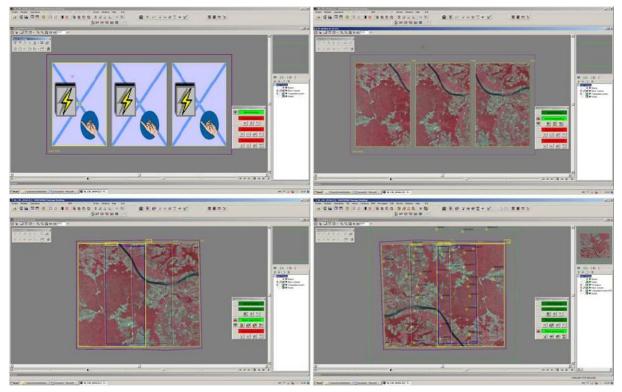

Figure 3. The digital photogrammetric workstation

Table 1. Hardware configuration

Component	Description
Central processor (CPU)	Intel® Core™ 2 Duo CPU 2.94 GHz
System memory (RAM)	4 GB (3 GB usable)
Hard disk drive (HDD)	Toshiba DT01ACA100 ATA Device 1000 GB
Graphic card	NVIDIA GeForce 9800 GT
Display	Hyundai IT W220S - 3D stereomonitor. Hyundai *'interlaced'* stereoglasses.
Manipulators	Conventional mouse and keyboard
Operating system	Microsoft Windows 7

Project workflow description

The photogrammetric measurement was carried out in the stereomodels of CIR digital images of 30 cm GSD and 10 cm GSD using DPW with PHOTOMOD Lite software. Two modules of PHOTOMOD Lite software were used: (I) Montage Desktop to create stereomodel projects, and (II) StereoDraw to collect 3D vector objects (tree tops, crown areas). Additional data processing was performed using DEM and Global Mapper software.
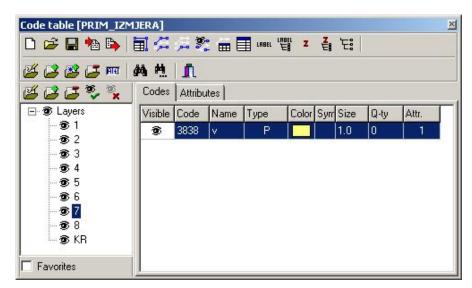
Project creation

The projects were created using four main steps (Block forming, Aerial triangulation, Block adjustment and Block processing) of Project Manager in Montage Desktop module (Figure 4). During first step (Block forming) images were added to the projects, and positioning (rotation) of images and the whole blocks are conducted. Then was followed Aerial triangulation which included defining camera parameters and the interior orientation of the images. The exterior image orientation was carried out during the third step - Block adjustment. Block processing was the last step in project formation when StereoDraw module for further processing was chosen.

Figure 4. An example of project creation from three images of 30 cm GSD through four main steps: top left - Block forming, top right - Aerial triangulation, bottom left - Block adjustment, bottom right - Block processing.

Code table creation

Before creating and collecting vector objects in StereoDraw module, code table was created in which each object (tree top, delineated crown area) was described by a code name, code number, shape, colour, symbol and additional attributes if that was necessary.

Figure 5. An example of code table created for photogrammetric measurement. Layers from 1 to 8 present numbers of sample plots and were intended for collecting point objects (tree tops), while polygon objects (crown areas) were collected in Layer KR.

Photogrammetric measurement

The first part of photogrammetric measurement and photointerpretation was done in the StereoDraw module. Photogrammetric plots were 'set up' based on the spatial coordinates (x, y) of centers of terrestrial plots recorded by the GPS receiver during terrestrial measurement (Figure 6). In total, measurement on 183 sample plots was carried out.
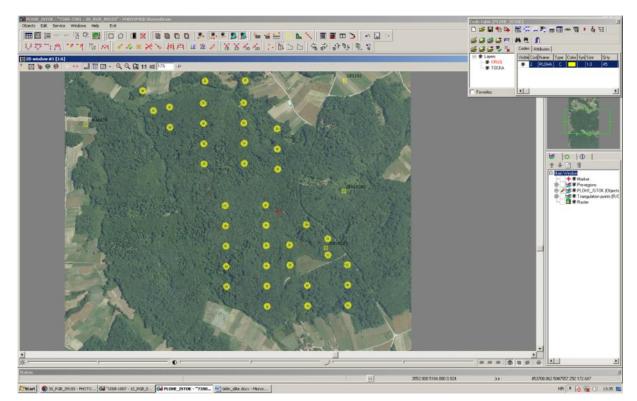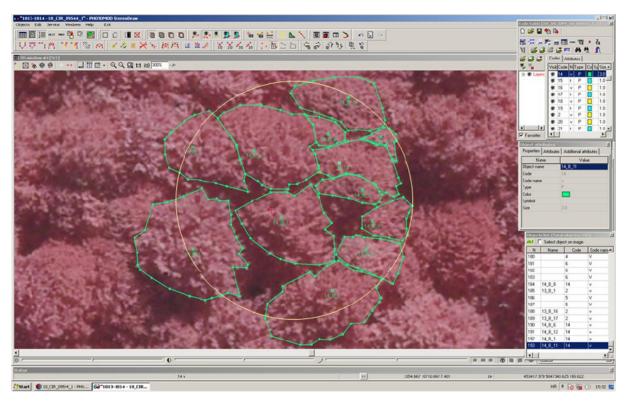

Figure 6. A systematic pattern of circular sample plots shown in the part of research area (subcompartment 17)
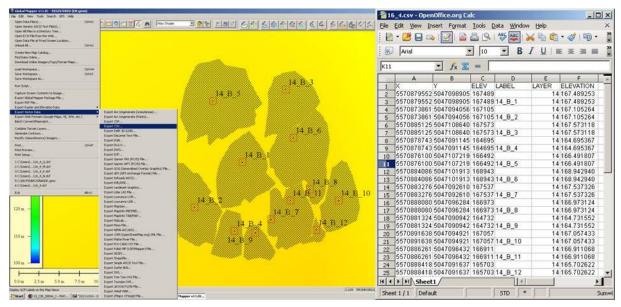
The determination of tree species and crown (tree) tops, as well as the crown delineation, was performed for each tree on each plot. Species determination was done by visual interpretation based on the general appearance of tree crowns (form, structure and crown texture) and crown colour. The crown (tree top) of each tree, with its top falling inside the circular sample plot, was determined and marked by placing a stereo-marker on it and creating a 3D point object with x, y, z coordinates. Each point, representing a single tree top, was labeled with a unique code (e.g. 14_B_1 – plot number, tree species (beech), tree number). Finally, the crown area of each tree on the plot was manually delineated, represented by a polygon object and labeled with a unique code. The data collected with the StereoDraw module were recorded and stored in .dxf file format.
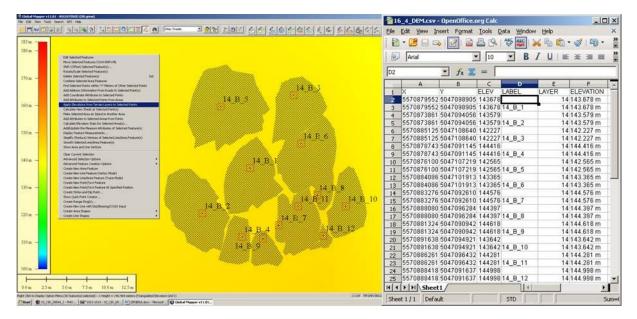

Figure 7. An example of a photogrammetric measurement of stand structure elements shown in model of CIR digital aerial images of GSD 10 cm in 2D window of StereoDraw module at magnification of 300 %.
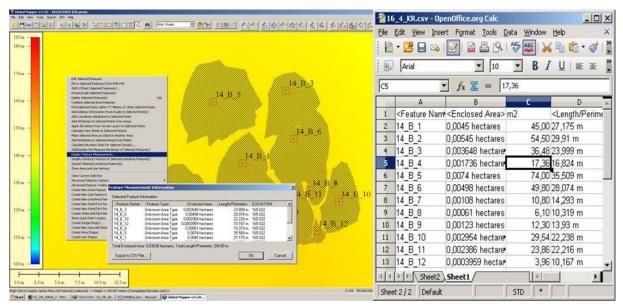
The data from .dxf files were then uploaded as the "trees" layer into the Global Mapper software using the preloaded DEM as a background layer and a reference for obtaining necessary data to calculate the photogrammetric tree height and crown area (Figure 8-10).

Figure 8. An example of exporting elevation coordinates of tree tops into the .csv format (*Export Vector Data → Export CSV*). Right: The corresponding exported data collected in OpenOffice.

Figure 9. An example of exporting elevation coordinates of trees' "botoms" (i.e. the elevation of the orthogonal projection of tree top points) from the associated tree top points and DEM into the .csv format (*Apply Elevations from Terrain Layers to Selected Points → Export Vector Data → Export CSV*). Right: The corresponding exported data collected in OpenOffice.

Figure 10. An example of exporting crown areas into the .csv format (*Display Feature Measurements → Export to CSV file*). Right: The corresponding exported data collected in OpenOffice.

Data Processing

To calculate photogrammetric tree diameters at breast height (DBH), regression models built by Balenović et al. (2012) were used. Models were built for the main tree species of the research area using a multiple linear regression analysis with crown diameter (D) and tree height (h) as independent variables:
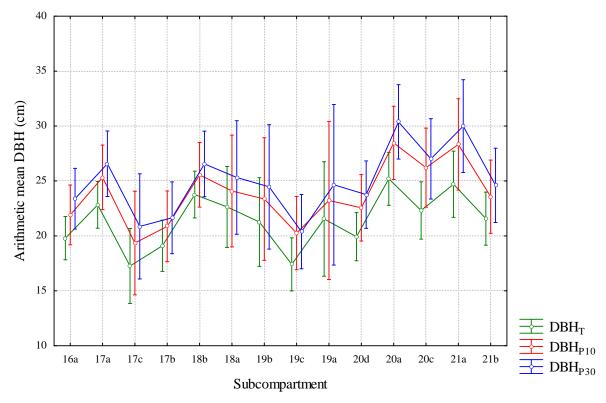
$$DBH = b_0 + b_1 D + b_2 h.$$

The photogrammetric height (h) of each tree on each plot was calculated as a difference between exported elevations of tree's top (Figure 8) and 'bottom' (Figure 9). The photogrammetric crown diameter (D) was calculated by applying the formula for circle surface area from the photogrammetrically measured and exported crown surface area (Figure 10).

For the purpose of data comparison, the arithmetic means of DBH for each subcompartment (stand) estimated by different methods were calculated: for the terrestrial (DBH_T), and for photogrammetric measurements on digital aerial images of 30 cm GSD (DBH_{P30}) and of 10 cm GSD (DBH_{P10}). Also, in order to evaluate the accuracy of photogrammetrically estimated DBH, deviations (Δ) of photogrammetrically estimated arithmetic means of DBH, in relation to the results obtained by terrestrial measurements, were calculated for each subcompartment (Table 2).

Output results description

Table 2. The subcompartments' arithmetic mean DBH estimated by terrestrial (DBH_T) and photogrammetric measurement (DBH_{P10}, DBH_{P30}) with errors of photogrammetric measurements presented through deviation from terrestrial measurement (Δ_{10}, Δ_{30})

Subcom-partment	DBH_T	DBH_{P10}	DBH_{P30}	Δ_{10}	Δ_{30}
	cm	cm	cm	cm	cm
16a	19.79	21.91	23.38	2.12	3.59
17a	22.83	25.33	26.57	2.50	3.74
17b	19.10	20.87	21.65	1.77	2.55
17c	17.26	19.35	20.86	2.09	3.60
18a	22.64	24.09	25.32	1.45	2.68
18b	23.76	25.56	26.55	1.80	2.79
19a	21.54	23.23	24.66	1.69	3.12
19b	21.26	23.36	24.46	2.09	3.20
19c	17.41	20.25	20.39	2.84	2.98
20a	25.20	28.47	30.38	3.27	5.18
20c	22.32	26.22	27.01	3.90	4.70
20d	19.93	22.56	23.76	2.63	3.83
21a	24.71	28.33	30.00	3.62	5.29
21b	21.57	23.58	24.60	2.00	3.03
Average				2.41	3.59

Figure 11. The subcompartments' arithmetic mean DBH estimated by terrestrial and photogrammetric measurements. The dots are the estimated arithmetic mean DBHs and vertical lines present 95% confidence intervals.

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Based on this research, the following may be concluded:

- The used software (PHOTOMOD Lite, Global Mapper) are designed in 'user friendly' manner so that relatively low level of photogrammetry and GIS expertise is needed for conducting photogrammetric measurement of stand structure elements. Of course, on the other hand sufficient level of expertise in forest inventory is needed.

- The PHOTOMOD Lite software enables simple creation of projects of digital images, easy manipulation with multiple digital images and projects, quick and easy collecting of 3D vector objects (tree tops, crown areas), and many other features that facilitate photogrammetric measurement and photointerpretation.

- Limitation of PHOTOMOD Lite in terms of number of images and quantity of vector data did not represent aggravating circumstance during this research, but for operational use that includes bigger area, commercial version of PHOTOMOD would be more suitable.

- The 'pattern of constant overestimation' of DBH obtained by photogrammetric measurement in relation to terrestrial measurement was noted for all subcompartments. The value of overestimation was lesser in case of aerial images of GSD 10 cm. Therefore, it is obvius that the application of aerial images of lower spatial resolutions due to lesser visibility of details (crown edges) increases the error in estimating DBH.

- The obtained results within this research concur with the results of previous research. However, unlike previous research, this research was conducted in privately-owned forests of a rather heterogeneous structure, with no timely management actions in the past, which means a more demanding photogrammetric measurement and photointerpretation. So, it can be assume that the applied method may obtain satisfying results in managed forests, with a more regular distribution of trees, regular crown shapes and significantly lesser share of overlapping. Also, it may find operational use in primarily in forests of less intensive management where a compromise between data collection costs and utilization value is necessary.

- Finally, operational use of PHOTOMOD and digital images of high spatial resolution in forest inventory is promising, but further research is necessary to examine the results and the commercial validation of applying the presented method when estimating other structural elements of forests (tree height, tree number, basal area, volume, biomass, carbon stocks, etc.).

NOTICE:

Results of this research were published or are in publishing procedure within following articles:

1) Balenović, I., A. Seletković, R. Pernar, H. Marjanović, D. Vuletić, E. Paladinić, J. Kolić, M. Benko, 2011: Digital Photogrammetry – State of the Art and Potential for Application in Forest Management in Croatia. SEEFOR, 2 (2): 81-93.

2) Balenović, I., A. Seletković, R. Pernar, M. Z. Ostrogović, A. Jazbec, 2012: Regression models of dbh estimation for photogrammetric maesurement. Šumarski list, 136 (3-4): 129-139.

3) Balenović, I., H. Marjanović, K. Indir, D. Vuletić, M. Z. Ostrogović, M. Benko, 2013: Estimation of the Stand's Arithmetic Mean Diameter using Manual Method of Digital Photogrammetry. Periodicum Biologorum, 115 (3): (accepted, in print).