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SHORT COMMUNICATION

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Using high resolution UAV imagery to estimate tree variables in *Pinus pinea* plantation in Portugal

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Abstract

Aim of study: The study aims to analyse the potential use of lowcost unmanned aerial vehicle (UAV) imagery for the estimation of *Pinus pinea* L. variables at the individual tree level (position, tree height and crown diameter).

Area of study: This study was conducted under the PINEA project focused on 16 ha of umbrella pine afforestation (Portugal) subjected to different treatments.

Material and methods: The workflow involved: a) image acquisition with consumer-grade cameras on board an UAV; b) orthomosaic and digital surface model (DSM) generation using structure-from-motion (SfM) image reconstruction; and c) automatic individual tree segmentation by using a mixed pixel-and region-based algorithm.

Main results: The results of individual tree segmentation (position, height and crown diameter) were validated using field measurements from 3 inventory plots in the study area. All the trees of the plots were correctly detected. The RMSE values for the predicted heights and crown widths were 0.45 m and 0.63 m, respectively.

Research highlights: The results demonstrate that tree variables can be automatically extracted from high resolution imagery. We highlight the use of UAV as a fast, reliable and cost-effective technique for small scale applications.

Keywords: Unmanned aerial systems (UAS); forest inventory; tree crown variables; 3D image modelling; canopy height model (CHM); object-based image analysis (OBIA), Structure-from-Motion (SfM).

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Introduction

Tree structure is a key issue for the understanding of many aspects of plant ecology and is also essential for the characterization and monitoring of cone production of *Pinus pinea* L. (Calama *et al*., 2008). Recent developments of operational small unmanned aerial vehicles (UAV) eased their extensive use in forestry, as both the spatial and temporal resolution of UAV imagery suit better local-scale investigation than traditional remote sensing tools (Bohlin *et al*., 2012; Lisein *et al*., 2013). UAV imagery emerged as a feasible alternative for the monitoring of the three-dimensional (3D) structure of forests (Puliti *et al*., 2015). Structure-from-Motion (SfM) techniques allow to extract 3D-information of UAV flights, providing 3D point clouds on the basis of feature matches within overlapping images (Fritz *et al.*, 2013). From the 3D point cloud, a digital terrain model (DTM), a digital surface model (DSM), and a canopy height model (CHM) –computed by subtracting DTM from DSM– can be obtained, and individual tree attributes can be measured in the same way that processing ALS (Airborne Laser Scanning) data (Nurminen *et al.*, 2013).

In Portugal, new irrigation and fertilization experiments were established in 2013 within the framework of PINEA project. This research explores the performance of high spatial resolution UAV imagery to estimate tree height and crown dimensions under different treatments. An individual tree crown approach was performed in *P. pinea* stands, since could be valuable to examine the variation in the height and size of the crowns, required as input for single-tree level modelling of growth and cone production.

Materials and methods

Study area

This study was conducted in the private forest of 'Esteveira', close to Alcochete in the center of Portugal (Figure 1a). The trial was established over an area of 16 ha umbrella pine (*P. pinea*) forest plantation (Figure 1b), using a randomize design with 2 blocks, subjected to 3 treatments: control and two different levels of fertirrigation. Trees were planted in rows of 8 × 10 m in 1992-1993. In 2013 a systematic thinning was conducted producing a final density around 63 stems ha^{-1} in rows of 10 x 16 m, in order to form an open canopy of scattered trees. The trial site is characterized by fairly flat terrain (slopes from 0 to 6%, elevations from 78 to 92 m.a.s.l) and no understory.

Field measurements

Individual tree height and crown width were measured to the nearest decimetre with a Vertex III hypsometer (Haglöf, www.haglof.se) in a subsample of 52 trees (Table 1). To measure crown diameters, the Vertex was positioned just below the crown projection, in each main cardinal extreme, to obtain two cross records (North-South and East-West directions).

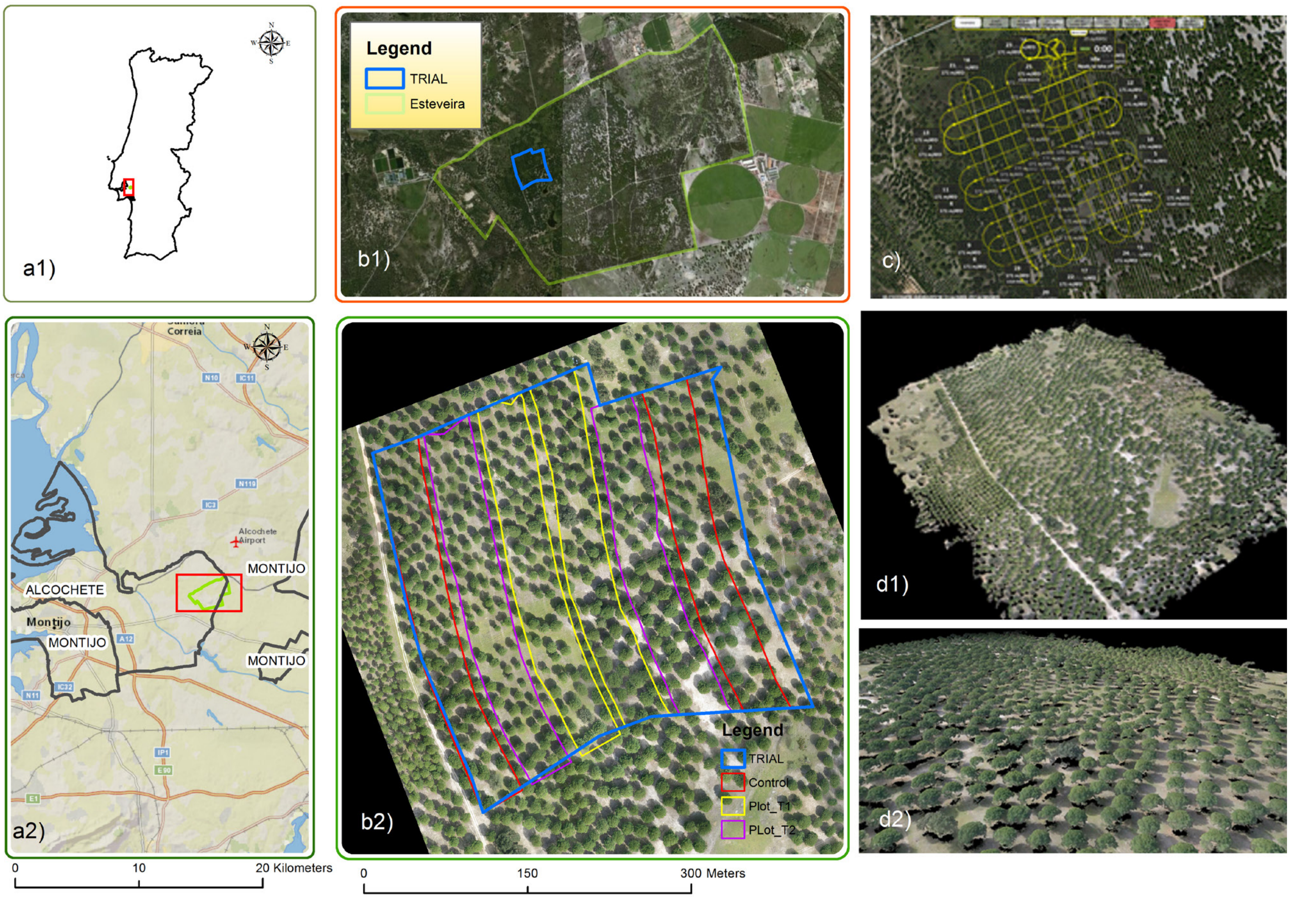

Figure 1. a) Location and boundary of the 'Esteveira' forest study site (green line) b) Trial (blue line) with the locations of the different plots (red, yellow and magenta polygons) c) Flight design d) Examples of DSM from the photogrammetric processing of the UAV imagery.

Table 1. Summarised data from field and image-measured sample plots.

Plot	*N*	*d*				*h*				*Cw*				*h_UAV*				*Cw_UAV*			
		mean	min	max	SD	mean	min	max	SD	mean	min	max	Sd	mean	min	max	SD	mean	min	max	SD
1	19	42.69	31.15	53.60	5.63	10.41	8.70	12.10	0.84	10.88	8.62	13.66	1.32	10.18	8.17	11.84	0.88	10.71	8.40	13.33	1.27
2	16	40.63	30.90	49.35	4.84	9.76	7.00	12.00	1.21	9.95	6.74	12.83	1.59	9.06	7.04	10.77	1.02	9.87	6.80	12.40	1.54
3	17	42.52	36.40	48.45	3.34	9.81	8.20	11.90	0.98	10.38	8.71	12.64	1.18	9.37	7.32	10.89	0.84	10.25	8.54	12.54	1.25

N: field-measured number of stems in the plot, *d*: field-measured diameter at breast height (1.3 m above ground, cm), *h*: field-measured tree height (m), *h_UAV*: image-measured tree height (m), *Cw*: field-measured crown diameter (m), *Cw_UAV*: image-measured crown diameter (m), min: minimum value, max: maximum value, SD: standard deviation.

Overall description of the method

The workflow is shown in Figure 2. Firstly, the flight planning and monitoring software eMotion 2 V. 2.4.2 was used to determine the main flight parameters (office-planning phase) (Figure 1c). Secondly, five ground control points (GCPs) were marked to georeference the output 3D models in the photogrammetric processing (First phase, Figure 2).

Thirdly, images were processed to obtain DSM (Figure 1d). DSM point clouds were classified into ground and non-ground points using Postflight Terra 3D (pix4D, ®Ecublens, Switzerland). Non-ground points were removed using an automatic object classification followed by a subsequent manual refined to remove the remainder noise. Fourthly, the natural neighbour interpolation technique implemented in Postflight Terra 3D was employed to generate the DTM using the ground points. Fifthly, a CHM was obtained by subtracting the DTM from the DSM using QGis V. 2.2.0 (Second phase, Figure 2).

Finally, an object-based image analysis (eCognition Developer 8.7 (®Trimble Gmbh, Munich, Germany)) was applied for the individual crown delineation and field and image-based measurements of the individual tree variables were compared (Third phase, Figure 2).

Image Acquisition and Pre-Processing

The airborne campaigns were conducted on March 12, 2015, using an RGB camera and the fixed-wing UAV SenseFly eBee operated by Terradrone Co. The RGB camera was a Canon Powershot S110 with a 4000 × 3000 pixel detector capturing images at ISO200 and 1/2000 seconds with a 5.320 mm focal length and sensor dimension of 7.4 x 5.58 mm. The UAV weighs approx. 700 g with payload, and has a maximum operational flight time of approx. 45 min.

The flight plan covered the entire study area with a lateral and longitudinal overlap of 80 and 75%, respectively. The flight line spacing was 48 m and the average altitude above ground level was 170 m (Figure 1b). Two perpendicular flight lines were flown in order to improve the accuracy. Each picture covered an area of 240 x 180 m.

A set of 190 images were analysed to generate each orthomosaic and DTM/DSM for the trial. We used

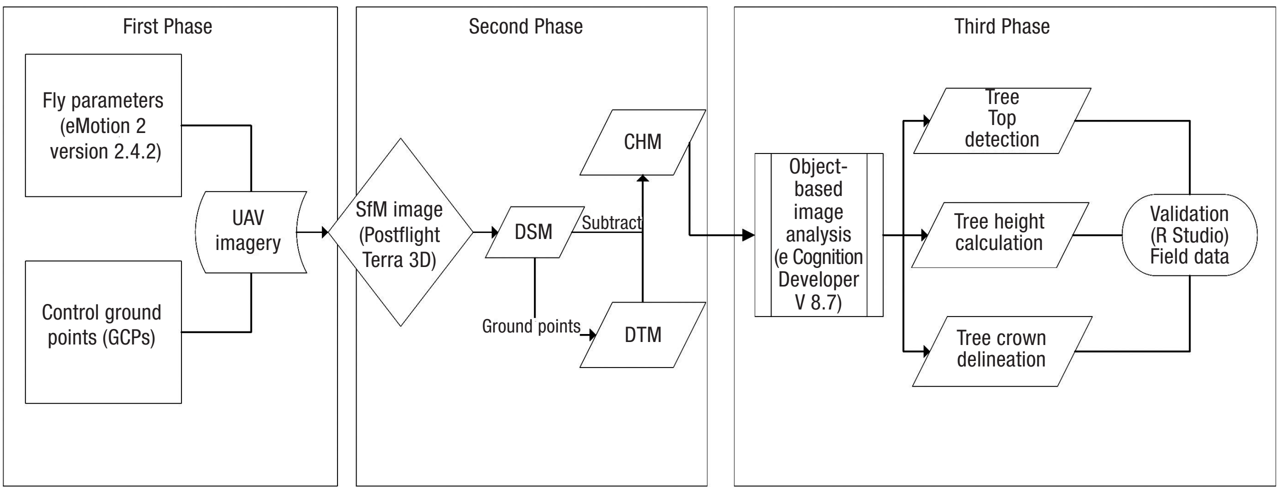

Figure 2. Flow chart of the implemented process.

pix4D software (®Ecublens, Switzerland), that implements SfM technique for image reconstruction. The orthomosaic had high spatial resolution with ground sampling distance (GSD) values of 6.23 cm.

Calculation of tree variables

Tree position, height, and crown width was retrieved from the CHM by using a modified version of the mixed pixel-and region-based algorithm designed by González-Ferreiro *et al*. (2013). This algorithm is proposed as a sequence of routines programmed in the integrated development environment (IDE) (eCognition Developer 8.7 (®Trimble Gmbh, Munich, Germany)). All logical procedures in the construction of the canopy delineation algorithm were arranged into five groups: CHM smoothing, segmentation, classification of canopy areas, iterative process, and data export. For this study, some parameters of the algorithm have been tuned, since the size and shape of *P. pinea* crowns widely differ from those crowns of *Pinus radiata* D. Don for which the algorithm was originally designed. Thus, a CHM resampling to 20 cm resolution and a subsequent smoothing with mean (5x5) and median filters (5x5) was conducted. Further, the initial maximum search domain in the iterative process (see the Figure 3 in González-Ferreiro *et al.,* 2013) was changed from 5 to 25, and only one interaction was applied. Crown delineation (Figure 3a) was then exported as vector polygons in an ESRI™ shapefile. Crown widths of the individual polygons were measured in two perpendicular directions (N-S and E-W) using QGis V 2.2.0. Tree tops and height attributes were exported as a point vector shapefile for subsequent analysis. Finally, linear fits and RMSE were computed comparing field and image-based measurements for the 52 sampled trees.

Results

Linear fits of the field and image-measured height showed an $R^2 = 0.81$ (rRMSE = 4.56%), while in crown diameter an $R^2 = 0.95$ (rRMSE = 6.14%) was achieved (Figure 3b). Detection rate was 100%. There were no false positives neither negatives in the sample area.

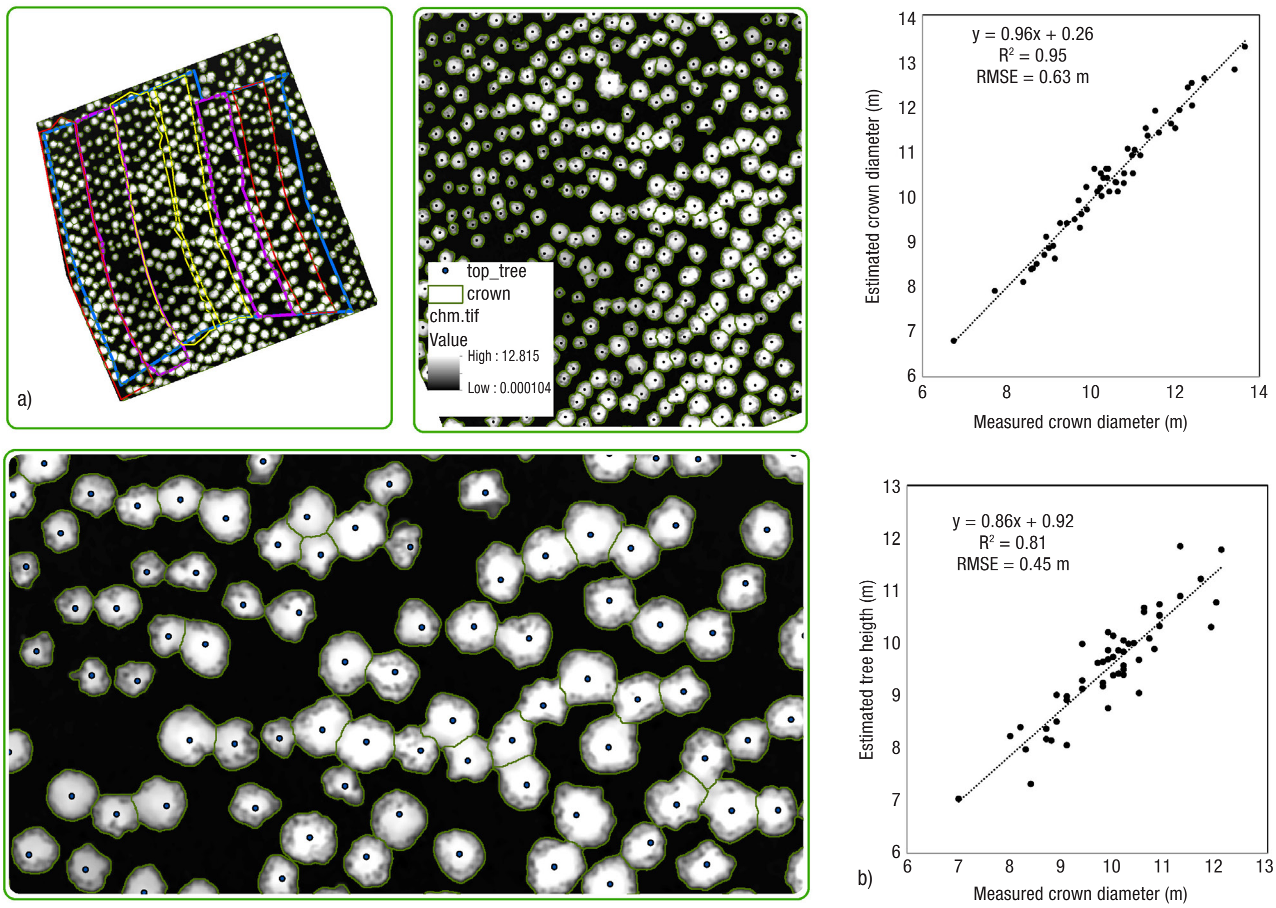

Figure 3. a) Examples of crown delineation with the location of tree tops in the trial. b) Linear fits between field and image-based measurements for the 52 sampled trees.

Discussion and conclusions

This study shows that *P. pinea* crown variables can be accurately modelled from high resolution UAV imagery. Tree heights and crown width estimations presented similar or higher performance that previous researches for palm plantation (Kattenborn *et al*., 2014) and olive orchards (Zarco-Tejada *et al*., 2014; Díaz-Varela *et al*., 2015). It is unclear if error source were field or imagery data since: *i*) accurate field measurement of the height of *P. pinea* is difficult, due to umbrella-shaped crown and lack of a clear apical dominance and *ii*) tree crown estimation from remote sensors could take into account tree irregularities ignored by the operator in field measurement (Moorthy *et al*., 2011).

It is important to note that this methodology was applied on flat terrain below sparsely distributed trees without the need of supplementary data points to generate the DTM. Results have demonstrated that forest inventories in *P. pinea* forests could be supplemented and updated with low-cost UAV imagery. In more dense vegetated areas a poorer performance is expected due to the impossibility of aerial photography for penetrating through vegetation and additional data could be necessary. Future research will replicate this experiment using a UAV-LiDAR system in order to compare its performance against the low-cost alternative presented here and also to enable crown delineation from UAV in more dense forests.

Finally, it is important to highlight that an UAV equipped with low-cost consumer grade cameras has the potential to provide large amounts of information for forest variables mapping at stand level (e.g density, canopy cover, stand volume, stand biomass, etc.) and might be used for surveying spatial variations in growth or estimate yield differences The present study also sets the basis for further research focused on the use of UAV multi-temporal imagery for forest growth assessment by means of time series in order to improve methods to monitor the development of *P. pinea* stands under different treatments.

References

Bohlin J, Wallerman J, Fransson JE, 2012. Forest variable estimation using photogrammetric matching of digital aerial images in combination with a high resolution DEM. Scand J For Res 27: 692-699. http://dx.doi.org/10.1080/02827581.2012.686625.

Calama R, Gordo FJ, Mutke S, Montero G, 2008. An empirical ecological-type model for predicting stone pine (*Pinus pinea* L.) cone production in the Northern Plateau (Spain). For Ecol Manag 255: 660-673.

Definiens AG, 2007. Definiens developer 7 reference book. Definiens AG, München, 195 pp.

Díaz-Varela RA, de la Rosa R, León L, Zarco-Tejada PJ, 2015. High resolution airborne UAV imagery to assess olive tree crown parameters using 3D photo reconstruction: Application in breeding trials. Remote Sens 7: 4213-4232. http://dx.doi.org/10.3390/rs70404213.

Fritz A, Kattenborn T, Koch B, 2013. UAV based photogrammetric point clouds tree stem mapping in open stands in comparison to terrestrial laser scanner point clouds. Int. Arch. Photogramm. Remote Sens Spat Inf Sci 40: 141-146. http://dx.doi.org/10.5194/isprsarchives-XL-1-W2-141-2013.

González-Ferreiro E, Diéguez-Aranda U, Barreiro-Fernández L, Buján S, Barbosa M, Suárez JC, Miranda D, 2013. A mixed pixel-and region-based approach for using airborne laser scanning data for individual tree crown delineation in *Pinus radiata* D. Don plantations. Int J Remote Sens 34(21): 7671-7690. http://dx.doi.org/10.1080/01431161.2013.823523.

Kattenborn T, Sperlich M, Bataua K, Koch B, 2014. Automatic single tree detection in plantations using UAV-based photogrammetric point clouds. Int Arch Photogramm Remote Sens Spat Inf Sci XL-3: 139-144. http://dx.doi.org/10.5194/isprsarchives-XL-3-139-2014.

Lisein J, Pierrot-Deseilligny M, Bonnet S, Lejeune P, 2013. A photogrammetric workflow for the creation of a forest canopy height model from small unmanned aerial system imagery. Forests 4: 922-944. http://dx.doi.org/10.3390/f4040922.

Nurminen K, Karjalainen M, Yu X, Hyyppä J, Honkavaara E, 2013. Performance of dense digital surface models based on image matching in the estimation of plot level forest variables. ISPRS J Photogramm Remote Sens 83: 104-115. http://dx.doi.org/10.1016/j.isprsjprs.2013.06.005.

Moorthy I, Miller JR, Berni JAJ, Zarco-Tejada P, Hu B, Chen J, 2011. Field characterization of olive (*Olea europaea* L.) tree crown architecture using terrestrial laser scanning data. Agric For Meteorol 151: 204-214. http://dx.doi.org/10.1016/j.agrformet.2010.10.005

Puliti S, Ørka HO, Gobakken T, Næsset E, 2015. Inventory of small forest areas using an unmanned aerial system. Remote Sens 7: 9632-9654. http://dx.doi.org/10.3390/rs70809632.

Zarco-Tejada PJ, Díaz-Varela R, Angileri V, Loudjani P, 2014. Tree height quantification using very high resolution imagery acquired from an unmanned aerial vehicle (UAV) and automatic 3D photo-reconstruction methods. Eur J Agron 55: 89-99. http://dx.doi.org/10.1016/j.eja.2014.01.004.