Creation of a Canopy Height Model from mini-UAV imagery

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Bulleted list of abstract highlights:

- In forestry, low-altitude imagery from UAV (Unmanned aerial Vehicle) can be used to characterize forest structure through a Canopy Height Model (CHM).

- The goal is to develop a new methodology for building CHM based on UAV photogrammetry.

- An UAV is used to acquire aerial images, whereas tree heights are measured on the field.

- The Digital Surface Model (DSM) is generated by means of Computer Vision and photogrammetric softwares. Combined with a Digital Terrain Model (DTM), it produces a CHM. Tree heights measurements are then used to validate the resulting CHM.

- CHM of good precision (RMSE single tree height of 2.1 m) and very good resolution (25 cm) is generated.

- Due to the Digital Terrain Model's low accuracy, the CHM created is not accurate enough to measure single tree height. Nevertheless, this workflow enables quick acquisition of valuable information at the stand level.

Extended Abstract:

The arrival of mini-UAV, these small autonomous aircrafts, has opened the doors to a new environmental data acquisition's approach. In forestry, low-altitude imagery from UAV can be used to characterize forest ecosystem structure through a Canopy Height Model (CHM). The greatest asset of these images,

compare to traditional remote sensing techniques such as photogrammetry (high altitude flights with metric camera) or Lidar based survey, stay its high spatial and temporal resolutions.

In this research, authors developed a new workflow for acquiring low-altitude aerial images with a mini-UAV and used them for the construction of a high resolution Canopy Height Model. The study area is a 130 ha broadleaf forest located in Grand-Leez, Belgium. Stands are mixed, uneven-aged and the main species is oak (*Quercus robur* and *Quercus petraea*). By using the UAV Gatewing X100 (http://www.gatewing.com) and the consumer grade camera Ricoh GRIII (10 Mpixels, 6 mm fixed focal length), 612 aerial images covering the entire study area were collected in one single flight. The flight altitude was 250 m height, providing 8 cm Ground Sample Distance (pixel resolution) and 80 % side and forward overlaps.

For digital photogrammetry processing, authors compare two software solutions. The first one is the recently launched (commercial) Computer Vision: Agisoft Photoscan Software (http://www.agisoft.ru). The second one is an open source toolbox for experimental photogrammetry developed by the National Geographic Institute of France: MicMac (http://www.micmac.ign.fr/). The workflow was conducted for each software and the strengths and weaknesses were then compared. At first, the amateur camera has been calibrated to take into account lens distortion. Afterwards, relative orientation of the block of low altitude images has been computed (Bundle adjustment) using an automatically determined tie points. Geo-referencing was then performed using 5 ground control points. Subsequently, a Digital Surface Model was generated by dense matching algorithms (ray intersection). Eventually, a low resolution Digital Terrain Model (10 m resolution DTM generated from topo data) was co-registered with the UAV-photo DSM and the height of the vegetation was computed as the difference between the DSM and the DTM.

Validation of the two Canopy Height Models (one for each software) was achieved by comparing field measurements of the tree heights with the CHMs. Trees with easily recognizable crown on the aerial images were selected for covering the entire forest and their heights were measured on the field with a Vertex IV clinometer (n=137). The highest pixel value for each tree crown was determined with CHMs and residuals were computed (equation 1). According to authors, these residuals have four origins: 1) the Digital Terrain Model used with its poor resolution and unknown accuracy has marred the precision of the Digital Surface Model, 2) 3D reconstruction from images is tricky for objects such as forest canopy because of leaves movements and the repetitive texture of canopy in broadleaf forests that both hinder the process of dense matching 3) The result of DSM and DTM co-registration for forested area is not scientifically rigorous, due to the lack of ground visibility (vegetation height =0) on the DSM and 4) on field measurements of the tree height are prone to error, owing to the difficulty of visually determining the top of the tree from the ground. The low resolution of the DTM is the major cause of CHM uncertainty, therefore better results can certainly be achieved using a Lidar-DTM instead of topo-DTM.

$$H_{CHM} - H_{field} = \Delta H \qquad (1)$$

with

H_{field} = *Tree Height measured on the field*

$H_{CHM} = Tree\ Height\ measured\ on\ the\ Canopy\ Height\ Model$

$\Delta H = Residuals\ of\ the\ Canopy\ Height\ Model$

The resulting CHMs (Figure 1) of 25 cm resolution enable the computation of single tree height with an RMSE of 2.1 meters. Although, even though the two softwares are presenting a lot of operational differences, the two resulting CHMs are not significantly different. Photoscan interface is really intuitive and processing in Photoscan is faster than in MicMac. On the opposite, MicMac offer the opportunity to the user to define a lot of parameters that enable a finer control of each step of the workflow (Camera calibration - Tie points - Orientation - geo-referencing and dense matching). We recommend to experienced scientists with a background in photogrammetry to use Micmac. For novice users without high precision requirement, we advocate the use of Photoscan.

Even if the accuracy of the resulting UAV-photo DEM is not good enough for measuring single tree height with this method, valuable characteristics at the stand level could now be quickly available with such a workflow. Indeed, stand level information such as recruitment state, maturity level (e.g. mean height, dominant height, etc.), and horizontal and vertical structure variability could be analyzed from such CHMs.

This research highlights the fact that UAV photogrammetry which is using consumer-grade digital camera and Structure from Motion software must be improved before being able to provide very accurate Digital Elevation Model of forest canopy. Indeed, measurement of tree height increment based on multi-temporal UAV flights, for example, is not conceivable with a CHM precision of less than one meter. Nevertheless, UAV-photogrammetry is a very promising approach that may obtain satisfying results for a bunch of applications. Moreover, spectral information combined with the CHM will greatly improve the accuracy of forest structural data extraction. Rapid generation of CHM may bring a new way of acquiring up to date forest characteristics: at a finer spatial scale than photogrammetric techniques using high altitude imagery and with an unbeatable temporal resolution.
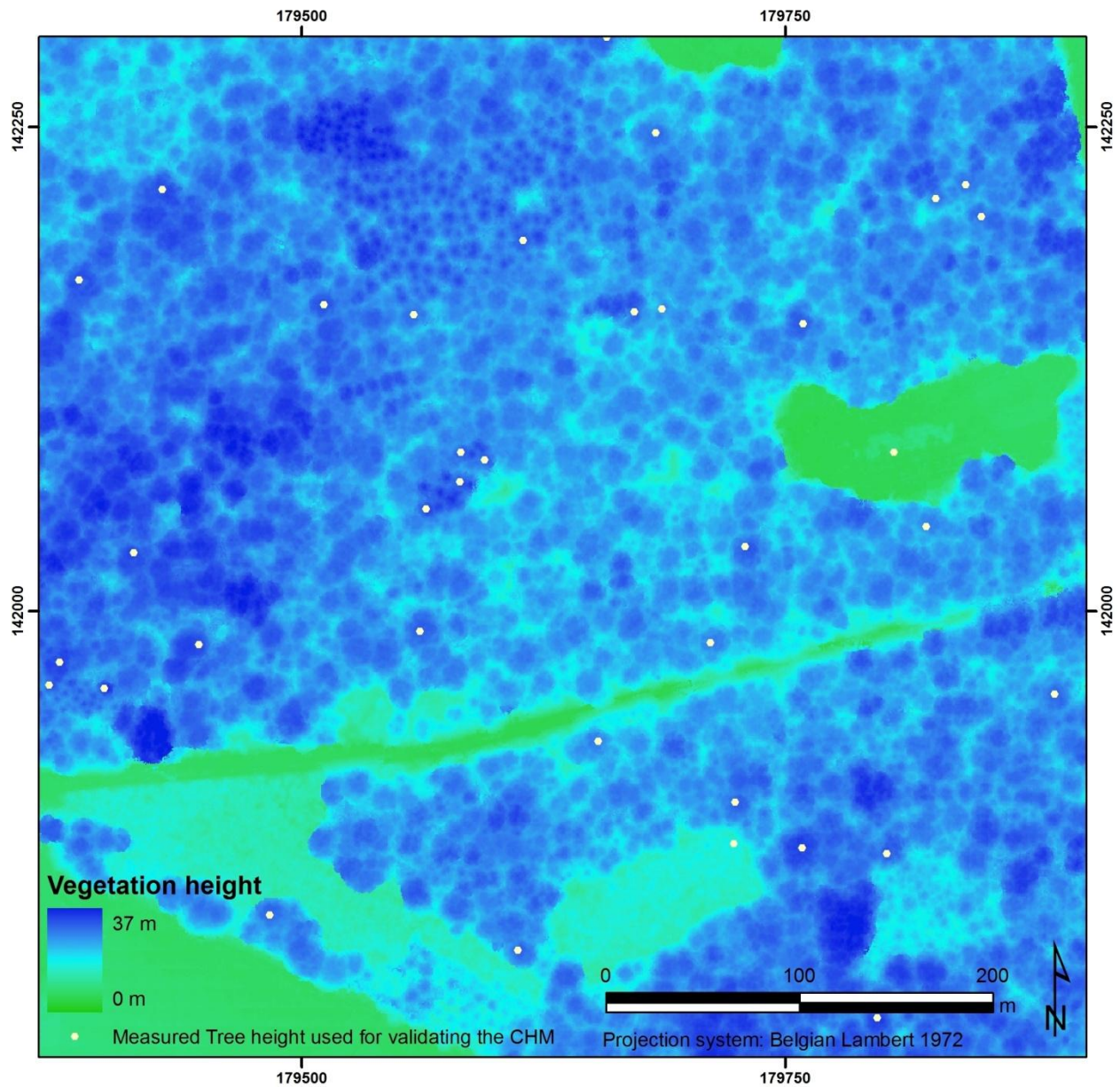
Figure 1 : UAV-photo Canopy Height Model (part of the study area). The white circles show the localization of measured tree heights which have been used for validating the CHM.