DIRECTIONAL LOCAL FILTERING ASSISTING INDIVIDUAL TREE ANALYSIS IN CLOSED FOREST CANOPIES USING VHR OPTICAL AND LIDAR DATA

F. M. B. Van Coillie [a, *], F. Devriendt [a], R. R. De Wulf [a]

[a] FORSIT – Laboratory of Forest Management and Spatial Information Techniques, Faculty of Bioscience Engineering, Coupure Links 653, 9000 Gent, Belgium - (frieke.vancoillie, flore.devriendt, robert.dewulf)@ugent.be

KEY WORDS: directional local maxima and minima, tree detection, tree delineation

ABSTRACT:

Providing accurate resource information at the individual tree scale in an automated, computerized way is not only challenging for researchers, it is highly relevant for diverse forest organisations and management agencies. We present a conceptual approach to extract tree crowns by using directional local filtering (DLF). The motivation for a directional approach is driven by the objective of finding locally connected extrema within closed forest canopies with multiple strata. We developed DLF based on high resolution optical artificial imagery and applied the filter to the LiDAR-derived CHM of the oldest forest reserve in Flanders (Belgium), Kersselaerspleyn. Comprehensive testing on VHR optical imagery suggested that DLF allowed for individual tree identification. Moreover, by scanning the 3D canopy line-wise in different viewing angles, locally connected maxima and minima were detected. The extracted local maxima and minima could subsequently be used to seed and bound region growing when delineating tree crowns. DLF could thus be considered as a pre-processing step prior to tree delineation.

1. INTRODUCTION

In the context of sustainable forest management for multiple purposes, there is little doubt that the need for accurate and fine-scale resource information is still ongoing. In recent years, the efficiency with which such detailed forest information is collected steered remote sensing research towards the development of automated processes at the individual tree scale. The development of automated tree detection and delineation algorithms is a typical example that is not only the area of interest to researchers but likewise to forest organisations and management agencies. In the framework of the monitoring programme of the Flemish forest reserves, since the year 2000 INBO (the Flemish Research Institute for Nature and Forest) is collecting individual tree information via costly and time-consuming field campaigns. Given the associated high financial and human efforts INBO would greatly benefit from a more automated inventory process. As part of a larger research project we developed a crown delineation method seeking at mapping tree crowns for the purpose of discriminating and classifying tree species, estimating tree density and in a later phase understanding gap dynamics.

Research into automatic tree detection and delineation from digital imagery dates back to the mid-1980s. Generally, algorithms can be summarized in two different categories according to their purpose: tree detection algorithms and crown delineation algorithms. Although both categories are often intermixed, we follow the interpretation of Ke and Quackenbush (2011) who define tree detection as those processes that deal with finding tree tops or locating trees, and characterize tree delineation as automatically determining tree crown outlines. From this point of view, tree detection may serve not only as a goal in itself, it may also be considered as a necessary pre-processing step before tree delineation.

Most tree detection and delineation methods have been developed for high resolution optical imagery. When looking at the 3D view of high spatial resolution images over forested regions we typically can observe a mountainous surface. Especially for trees with a conical structure, bright peaks in the image correspond to tree tops because of the higher level of solar illumination. The reflectance decreases towards the crown boundaries, and the darker pixels surrounding the bright area correspond to the shaded area from the neighbouring tree crowns or from the bidirectional reflectance effect (Ke and Quackenbush, 2011). Therefore, algorithm developers converted the problem of detecting tree crowns to the problem of finding bright peaks in the image, while they shifted the problem of delineating crown boundaries to the problem of delineating the dark valleys.

In recent years, Light Detection And Ranging (LiDAR) data have emerged as important data source for extracting individual tree information (Chen et al., 2006; Holmgren and Persson, 2004). The high sampling LiDAR point data (including full waveform LiDAR) allows for the derivation of a 3D canopy height model (CHM). As LiDAR partially penetrates the forest canopy advanced processing of LiDAR data enables even the detection of understorey trees. A striking similarity between the 3D CHM and the 3D view of a high spatial resolution optical image is its mountainous spatial structure. Therefore the LiDAR-derived gridded CHM is often processed using algorithms closely related to detection and delineation methods designed for passive optical images (Holmgren and Persson, 2004, Popescu and Wynne, 2004; Koch et al., 2006; Chen et al., 2006; Hirschmugl et al., 2007; Wolf and Heipke, 2007).

Regardless of the algorithms or image types used, many studies reported that tree detection and crown delineation accuracy was highest for even-aged, even-sized, evenly spaced pure forest stands (e.g. Pouliot et al., 2005; Gougeon and Leckie, 2006).

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

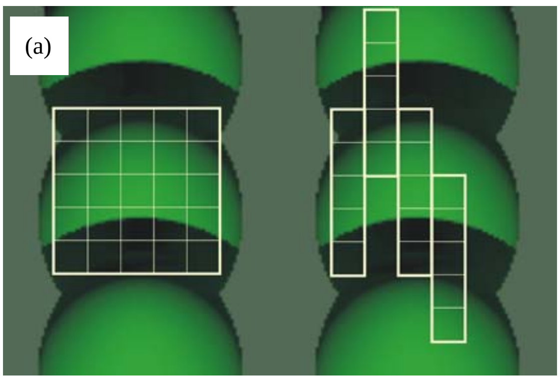
With the existing methods relatively great success can be achieved within managed forests, including natural or plantation conifer forests and orchards, with small species diversity and tree crowns that are typically symmetrical and circular in shape. However, in mixed-species forests of complex structure where trees occur in multiple strata and are closely packed, detection and delineation accuracy often drastically lowers (Bunting and Lucas, 2006). Tree detection and crown delineation thus remain a challenging research topic for naturally grown forests like the oldest forest reserve, Kersselaerspleyn, in Flanders, Belgium. Building on the crown delineation algorithm of Bunting and Lucas (2006) (designed for open forest and woodland environments and for CASI data) we present a variant of their technique by incorporating a novel tree detection algorithm, Directional Local Filtering (DLF), as a pre-processing step before tree crown delineation. While Devriendt et al. (2012) aim at highly accurate tree species maps using both hyperspectral CASI and LiDAR data, we focus on a sub-aspect of the method: optimised tree crown delineation using the LiDAR-derived CHM by including DLF.

2. DIRECTIONAL LOCAL FILTERING

2.1 DLF motivation

There are a number of different conceptual approaches to the problem of automated tree detection among which Local Maximum Filtering (LMF) is by far the most frequently reported method.

We present DLF as a variant of LMF. With DLF we aim to refine LMF by using a 1D window (line) and simultaneously looking for local minima. Both minima and maxima are given a physical meaning, respectively crown edges and crown apexes (Figure 1a.). Filtering line-wise instead of window-wise offers the opportunity of finding an increasing amount of local extrema (Figure 1b.). By means of filtering in different viewing angles, the chance of missing real extrema is minimized. Moreover, using different viewing angles has the advantage that not only more but also locally connected extrema are detected. Although the filter length of DLF still has to be tuned to the size of the tree crowns, it is less an issue given the increasing amount of detected extrema.



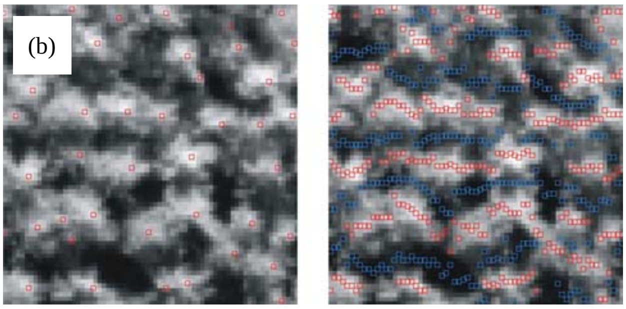


Figure 1. LMF versus DLF: (a) 3D window versus 1D line approach, (b) LMF maxima versus DLF maxima (red) and minima (blue).

Working with different viewing angles was steered by experiments we performed on artificially generated tree lanes. Figure 2 shows two identical artificial tree lanes that were rendered under perpendicular illumination conditions and cross profiles respectively parallel with and perpendicular to the illumination angle.

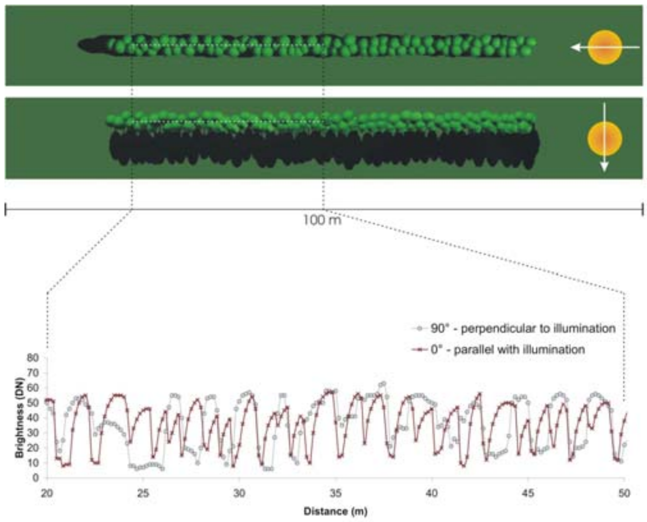


Figure 2. Artificially generated tree lanes under different illumination conditions and (part) of the corresponding cross profiles (taken after conversion to grey values)

From the profiles it can be seen that looking parallel to the illumination azimuth allows for individual tree identification. Looking perpendicular to the illumination azimuth results in a cross profile with reduced brightness dynamics, inducing the loss of some tree crowns. The more or less regular pattern of brightness peaks and valleys is no longer present in the perpendicular profile. Considering this, one might benefit from limiting image analysis to directions parallel with the illumination vector, because this direction will yield the highest contrast possible. On the other hand, when spatial and radiometric resolutions are sufficiently high or with higher sun elevations, one might actually benefit from including both viewing directions in the analysis, since these two viewing directions then produce profiles with a large amount of uncorrelated information. These two extreme situations stressed the importance of viewing direction when filtering line-wise. As we applied DLF to the LiDAR-derived CHM, illumination conditions are no longer an issue. However, filtering the mountainous CHM surface in two perpendicular directions will guarantee that all possible peaks and valleys are sampled.

2.2 DLF implementation

DLF was implemented in C++ using the Borland C++Builder (version 6.0). Graphical user interfaces were added to the programs in order to allow for easy application by potential non-technical users. The software operates on the Microsoft Windows platforms, and did not raise any particular computation or data storage issues.

2.3 DLF experimental setup

In a first stage, the DLF algorithm was developed using artificially generated very high resolution (VHR) optical images. Artificial image generation consisted of 1) modelling tree shapes, 2) generating multiple trees and placing them into stands, and 3) illuminating these forests using the Persistence of Vision Raytracer rendering algorithm to produce simulated VHR optical imagery (Van Coillie et al., 2001). Using artificially simulated images with varying number of trees, DLF was tested on its capacity to estimate stand density. Statistics of the distance between all two consecutive minima embracing a single maximum were used as explanatory variable for stand density.

In a second stage, real VHR imagery was used. A scanned color infrared aerial photograph (scale 1:5,000, October 1987, 25cm) covering part of a larger forest (650 ha) in Oud-Heverlee (Belgium) was orthorectified and degraded to four spatial resolutions, 50cm, 100cm, 200cm and 400cm, allowing to examine the influence of spatial resolution in the stand density estimation analysis. Besides, we used a panchromatic 1m resolution IKONOS image that is part of the global VHR coverage of the Flemish territory. The applied extract from the global coverage consisted of a mosaic of three images, recorded in the course of summer 2002 and covering part of the province of Limburg (Belgium).

Finally, since DLF proved to be suitable for individual tree analysis it was deployed to allocate locally connected maxima and minima on the LiDAR-derived CHM of the oldest forest reserve Kersselaerspleyn in Flanders (Belgium). Details about the Kersselaerspleyn study site and LiDAR CHM extraction are provided by Devriendt et al. (2012).

3. RESULTS AND DISCUSSION

3.1 *Stage 1*

Based on the artificially rendered images we found that three distance parameters show a strong logarithmic relation with stand density, with rounded R^2 values of 0.92, 0.87 and 0.87 for mean distance, standard deviation and number of collected distances (count) respectively (Figure 3). Based on these figures, we decided to select the mean distance between all two consecutive minima embracing a single maximum as an explanatory variable for stand density.

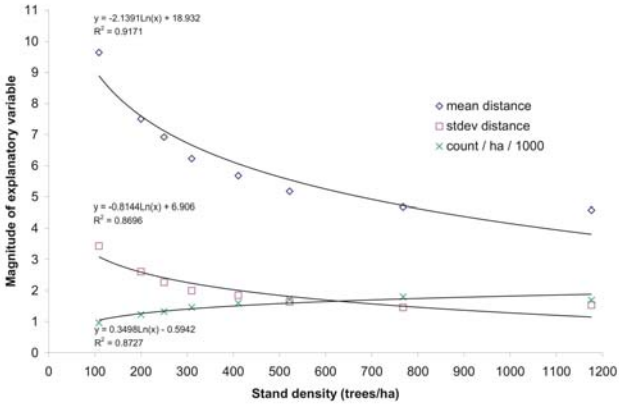


Figure 3. Stand density related to statistics derived from the distances collected after DLF filtering of the artificial imagery

3.2 *Stage 2*

Comprehensive testing, both real VHR imager types (aerial photograph and IKONOS image) of different spatial resolution, showed that DLF is generally outperforming LMF especially when radiometric and spatial resolution are rather low, and when analyzing directions parallel with and perpendicular to the illumination vector are combined.

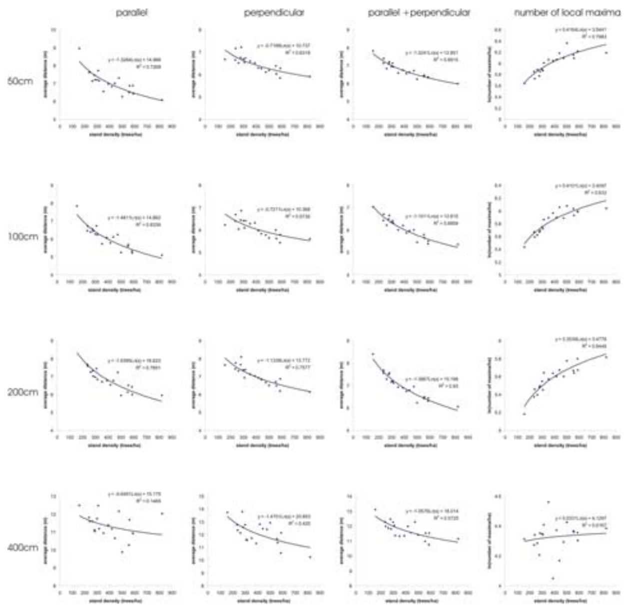


Figure 4. A comparison of the relation between stand density and from left to right: distances collected parallel with the illumination vector, perpendicular and in both directions; and the number of local maxima per ha, calculated on the scanned aerial photograph (LMF)

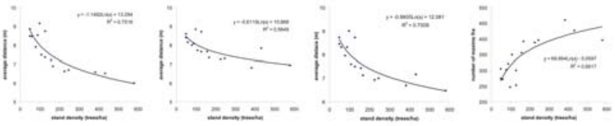


Figure 5. A comparison of the relation between stand density and from left to right: distances collected parallel with the illumination vector, perpendicular and in both directions; and the number of local maxima per ha, calculated on IKONOS imagery (LMF)

These results suggested that DLF allowed for individual tree identification and has potential to select local maxima and minima to seed and bound the region growing process when delineating tree crowns.

3.3 *Stage 3*

DLF filtering of the LiDAR-derived CHM resulted in locally connected mamima and minima. Compared to window-wise filtering line-wise filtering proved to have the advantage of detecting locally connected extrema. Figure 6 shows the DLF filtered local minima inside an exemplar tree cluster: only the local minima inside the tree cluster are visualized. Left we run the filter with a viewing angle of 0°, right an angle of 90° was implemented. It was clear that analyzing perpendicular directions delivered complementary information.

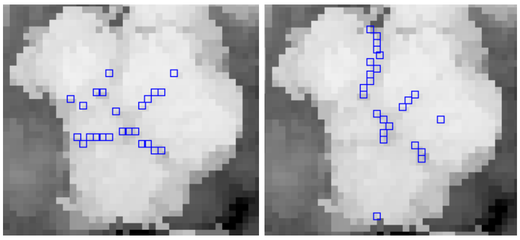


Figure 6. DLF of the LiDAR-derived CHM for the inner part of a tree cluster in two perpendicular directions: left with viewing angle = 0°, right with viewing angle of 90°

DLF was therefore considered as valuable variant of LMF for tree detection. As DLF served as a pre-processing step before crown delineation, two outputs of DLF are useful within the OBIA decision rule set of Devriendt et al. (2012) for CHM crown delineation: 1) the distances between all two consecutive minima embracing a single maximum; and 2) the locations of the locally connected maxima and minima. Both can be built in as criterion to seed and bound region growing in the OBIA crown delineation process (Devriendt et al., 2012).

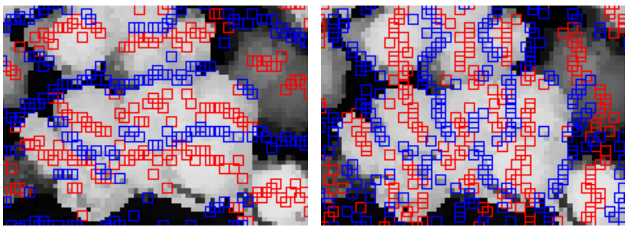


Figure 7. DLF of part of the LiDAR-derived CHM in two perpendicular directions: left with viewing angle = 0°, right with viewing angle of 90°(DLF maxima (red), DLF minima (blue))

4. CONCLUSION

A conceptual approach to extract tree crowns by using directional local filtering is presented. We developed the method as a variant of local maximum filtering aiming at optimised tree detection by using 1D instead of 3D window sizes. LMF was developed and tested on VHR optical imagery and applied to a LiDAR-derived canopy height model. In many circumstances, DLF outperformed LMF for stand density estimation thereby showing its potential for individual tree analysis. Finally, DLF served as a pre-processing step to CHM crown delineation: the distances between all two consecutive minima embracing a single maximum and the extrema locations themselves were promising parameters to steer subsequent crown delineation.

ACKNOWLEDGEMENTS

We gratefully like to acknowledge Afdeling Bos en Groen of the Ministry of the Flemish Community for providing the IKONOS imagery as well as the database with sample plots on which the Flemish Forest Inventory (Afdeling Bos en Groen, 2001) is based. We also thank VITO and RSL for pre-processing the LiDAR data. INBO is thanked for collecting and providing the field reference data. BELSPO provided funding through the Research Programme for Earth Observation Stereo II.

REFERENCES

References from Journals:

Bunting, P. and Lucas, R., 2006. The delineation of tree crowns in Australian mixed species forests using hyperspectral Compact Airborne Spectrographic Imager (CASI) data. *Remote Sensing of Environment*, 101, pp. 230 – 248.

Chen, Q., Baldocchi, D., Gong, P. & Kelly, M. 2006. Isolating individual trees in a savanna woodland using small footprint LiDAR data. *Photogrammetric Engineering and Remote Sensing*, 72, pp. 923 – 932.

Devriendt, F., Van Coillie, F.M.B. De Wulf, R.R., Bertels, L., Kempeneers, P., Vandekerkhove, K. and Morsdorf, F., 2012. Classification of unmanaged forest reserves in flanders (Belgium) at the tree crown level using airborne hyperspectral and LiDAR data. *Proceedings of GEOBIA 2012.*

Gougeon, F.A. and Leckie, D.G., 2006. Individual tree crown approach applied to Ikonos images of a coniferous plantation area. *Photogrammetric Engineering and Remote Sensing,* 72(11), pp. 1287 – 1297.

Hirschmugl, M., Ofner, M. and Raggam, J., 2007. Single tree detection in very high resolution remote sensing data. *Remote Sensing of Environment,* 110(4), pp. 533 – 544.

Holmgren, J. and Persson, A., 2004. Identifying species of individual trees using airborne laser scanner. *Remote Sensing of Environment*, 90, pp. 415 – 423.

Ke, Y. And Quackenbursh, L. J., 2011. A comparison of three methods for automatic tree crown detection and delineation from high spatial resolution imagery. *International Journal of Remote Sensing,* 32 (13), pp. 3625 - 3647

Koch, B., Heyder, U. & Weinacker, H. 2006. Detection of individual tree crowns in airborne LiDAR data. *Photogrammetric Engineering and Remote Sensing,* 72, pp. 357 – 363.

Popescu, S.C. and Wynne, R.H., 2004. Seeing the trees in the forest: using LiDAR and multispectral data fusion with local filtering and variable window size for estimating tree height. *Photogrammetric Engineering and Remote Sensing,* 70 (5), pp. 589 – 604.

Pouliot, D. A., King, D. J. & Pitt, D. G. 2005. Development and evaluation of an automated tree detection-delineation algorithm for monitoring regenerating coniferous forests. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere*, 35, pp 2332 – 2345.

Van Coillie, F.M.B., Verbeke, L.P.C. & De Wulf, R.R., 2011, Wavelet-based texture measures for semi-continuous stand density estimation from very high resolution optical imagery. *Journal of Applied Remote Sensing*, 5, 053560-1.

Wolf, B-M. and Heipke, C., 2007. Automatic extraction and delineation of single trees from remote sensing data. *Machine Vision and Applications*, 18, pp. 317 – 330.