Graph-Based Approach to Improve Individual Tree Crown Delineation in Temperate Forest using Structural And Spectral Information

Matthieu Deluzet, Thierry Erudel, Xavier Briottet, Thomas Houet, David Sheeren, Sophie Fabre

GRAPH-BASED APROACH TO IMPROVE INDIVIDUAL TREE CROWN DELINEATION IN TEMPERATE FOREST USING STRUCTURAL AND SPECTRAL INFORMATION

M.Deluzet[1], T.Erudel[1], X.Briottet[1], T.Houet[3], D.Sheeren[2], S.Fabre[1]*

[1] ONERA DOTA BP74025 - 2 av. Edouard Belin -31055 Toulouse, France; xavier.briottet@onera.fr, sophie.fabre@onera.fr
[2] Université de Toulouse, INRAE, UMR DYNAFOR; david.sheeren@ensat.fr
[3] LETG-Rennes COSTEL thomas.houet@univ-rennes2.fr
***** Correspondence: matthieu.deluzet@onera.fr; (M.D.)

ABSTRACT

Forest characterization at tree scale is possible with remotely sensed images of high spatial resolution. A first step is the Individual Tree Crown (ITC) delineation which corresponds to the segmentation of canopy cover into different tree crowns. In this study, a new method based on an initial watershed segmentation of Canopy Height Model (CHM) is proposed. This method is based on a graph transformation of the initial segmentation map in order to apply structural criteria (calculated owning to CHM) and spectral criterion (computed on red, green and blue bands). Adaptive thresholds are defined according to the studied forest characteristics in order to improve low quality segmentation cases. This method has been applied on a complex forest site (Broadleaf dominant, steep relief…). The results show a 17% increase of global performance in comparison to the reference watershed segmentation.

Index Terms— forest, individual tree crown, delineation, LiDAR, hyperspectral

1. INTRODUCTION

Forest observation is a global challenge, particularly in context of climate change. It is essential to understand forest biodiversity and its evolution. Today, high spatial resolution remote sensing data enable forest characterization at tree scale for mapping large area [1]. This cartography is complementary to ecologist works in the field, which give more precise information but limited to small studies areas. The major applications are tree resources inventory [2], vegetation health monitoring [3] and biodiversity study [4].

A preliminary step to work at tree scale is to delineate each Individual Tree Crown (ITC). This delineation is mostly achieved with Light Detection and Ranging (LiDAR) data which delivers structural information of the canopy (tree height, crown shape…) [5] [6].

LiDAR data can be processed to generate Canopy Height Model (CHM) in raster format, giving for each pixel the canopy height. This format makes easier the application of image processing methods [6], especially the watershed segmentation which is a method considering a gray scale image as a topographic surface [7] [8]. This method is particularly adapted to ITC delineation because height variations due to tree crowns are considered as a topographic surface. For instance, Barnes et al. [7] obtained from 70% to 92% of correct delineation of tree crown in a mixed forest using a watershed segmentation algorithm applied on CHM of various spatial resolutions (0.15, 0.25 and 0.5 m).

3D point cloud is a more complex format but give more precise information on the canopy structure than CHM. For instance, it is possible to observe sub-canopy trees [5]. For this reason, some methods have been developed to segment point cloud. The meanshift method is the most used. It consists of moving a kernel on the point cloud depending on density to find objects fitting with the kernel [9] [10]. Xiao et al. [9] obtained 81-87% of correct delineation in a mixed forest with a meanshift delineation method applied on point cloud with a density of 8 points/m². Some other methods have been tested, especially the normalized graph cut which improves an initial delineation by evaluating defined parameters (height variations, density variations…) calculated on point cloud [11].

The use of spectral information alone (RGB -Red Green Blue- or single spectral band image) for ITC delineation provided less quality delineation in comparison with structural information, especially because of exploitation due to the presence of shadow (particularly in forest with tall, tightly packed tree) and the complexity to differentiate tree crowns of the same species [12] [13]. However, the complementarity of spectral and structural information is a way to improve delineation performance [6] [14].

The delineation performance depends mostly of the forest type. The conical regular shapes of conifers make it easier to delineate than complex broadleaf crowns which can be more asymmetric. Some studies show that better performance is obtained on conifers even in a forest with mixed species [14] [15]. Tree density, crown overlap and relief influence delineation quality, especially for delineation based on structural parameters (tree height, crown shape…) which are directly impacted. It is important to develop robust methods applicable regardless to the forest type and the spatial resolution of the available data.

In this study, a new delineation method using structural and spectral information to enhance performance is introduced. This method is based on an initial CHM watershed segmentation considered as reference method. The study site, available data and the method are presented in section 2. The validation protocol is described in section 3 and the results in section 4, followed by a discussion (section 5).

2. MATERIALS AND METHODS

2.1 Study site

The study site is the Bernadouze forest located in the Pyrenees mountains on South-West of France (570950 E, 6190550 N, WGS 81 UTM zone 31 N, EPSG: 32631) and supported by the Labex DRIIHM (https://www.driihm.fr/) (Figure 1). This forest is mainly composed of beech trees. The broadleaf dominant species and the mountainous relief make this forest complex to delineate tree crowns.

2.2 Data set

LiDAR data have been acquired on the forest site and preprocessed in order to provide a 1 m spatial resolution CHM. Airborne hyperspectral data with 1 m spatial resolution and 3.6 nm spectral resolution covering the Visible Near Infrared (VNIR) spectral domain (414-974 nm) have been acquired by HySpex instrument (Norsk Elektro Optikk AS, lørenskog, Norway) and atmospherically corrected by Cochise atmospheric code [16] in order to provide spectral reflectance. CHM and hyperspectral image have been registered and each pixel corresponds to the same surface in both rasters. The RGB image is derived from hyperspectral data selecting three bands in the visible domain (red: 650 nm, green: 525 nm, blue: 450 nm).

The validation data set corresponds to 54 ITC delineated by photo-interpretation using RGB drone images with 5 cm spatial resolution. They are distributed throughout the area and selected in order to take into account the different crown sizes and positions (forest edge, heart of the forest with crown overlap and isolated tree).

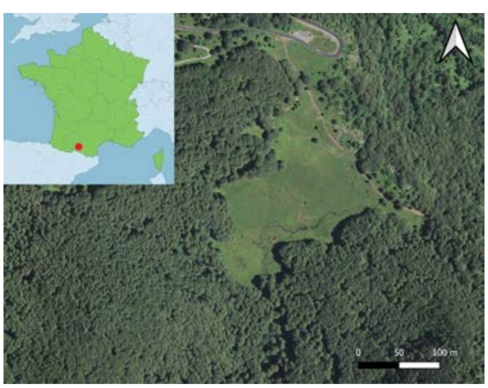

Figure 1: Bernadouze forest (IGN BD ORTHO® 50 cm)

2.3 Delineation method

Our method based on previous works [17] consists of a first segmentation step providing an initial delineation map, then improved by a graph-based approach using structural and spectral criteria (called decision criteria). Figure 2 presents a detailed diagram of the method.

The first step produces an initial delineation map by applying the watershed method from Scikit-image python package (https://scikit-image.org/) on the CHM filtered by a Gaussian filter. The Gaussian filter permits to smooth the CHM (reduction of noise) and to enhance height variations due to tree structure. A shadow mask calculated on hyperspectral data and a ground mask calculated on MNC are applied to the input data. The watershed method is considered as the reference for this study: results of the proposed method are compared to those obtained by the reference one.

The initial delineation map is then transformed into graph where each segment corresponds to a node and is connected with its neighbors by links. The graph format allows to easily apply decision criteria used to merge segments corresponding to the same tree crown. For each node of the graph, its related segment characteristics are calculated (maximum height, position, mean values in RGB image…). For each link between two nodes, the three following criteria are calculated:

- Planar distance between the maximum values of two neighboring segments.
- Height difference between the maximum values of two neighboring segments.
- Spectral distance between two neighboring segments using the Wasserstein distance [18] applied on RGB bands and implemented using the Scipy Package (https://scipy.org/).

This method is upgradeable by introducing new spectral and geometric criteria. A linear combination of those criteria is then calculated and compared to the following threshold:

$$\alpha*threshold_1+ \beta*threshold_2+ \gamma*threshold_3 \quad (1)$$

α, β, and γ are weights varying between 0 and 1 and their sum equal to 1. The three thresholds correspond to the three criteria and have to be defined depending on the forest characteristics (global height variations, typical crown diameter…). For each link between two nodes, the linear combination of equation (1) is evaluated. If the resulting value is higher than the threshold, the link is cut. The remaining nodes connected to each other, corresponding to the same crown, are then merged. This graph modification is then applied to the initial delineation map to obtain a final delineation map.

Thresholds are trained in a range of values defined by user. For the application on Bernadouze forest, values retained are between 1 and 6 m for *threshold1* (planar distance), between 0.1 and 0.5 m for *threshold2* (height difference) and between 0.008 and 0.01 for *threshold3* (spectral distance).

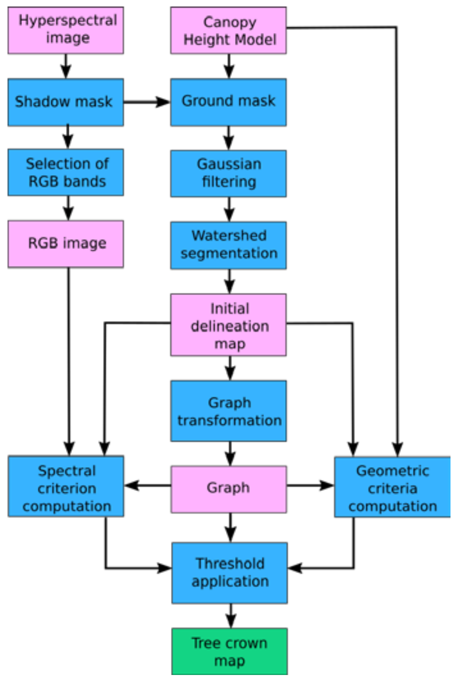

Figure 2 : Delineation method description (pink color: input and intermediary data, blue color: process stage, green color: output data)

3. PERFORMANCE EVALUATION

Two kinds of approach are proposed for the performance evaluation and do not require any field data.

The first evaluation approach is based on tree position comparison. The centroids of validation ITC and delineation segments are computed. For each centroid of validation ITC, the presence of segment's centroid inside circle with a fixed radius called limit radius is evaluated. The limit radius is fixed to 5 m according to the mean crown radius in the studied forest. The results are then classified into three categories:

- True Positive (TP) – One segment centroid is detected into the circle defined by the limit radius,
- False Negative (FN) – No segment centroid is detected into the circle defined by the limit radius,
- False positive (FP) – Several segment centroids are detected into the circle defined by the limit radius.

The second evaluation approach is based on recovery comparison between validation ITC and delineation segments. It is based on the proposed validation method from previous studies [8] [15] [18]. Delineation quality for each validation ITC is classed according to four categories:

- Matched – The validation ITC recovers more than 50% of a segment and this segment recovers more than 50% of the validation ITC,
- Missed – The validation ITC doesn't recover more than 50% of any segment,
- Over-segmented – The validation ITC recovers more than 50% of several segments,
- Under-segmented – A segment recovers more than 50% of the validation ITC but the validation ITC doesn't recover more than 50% of the segment.

The number of correctly delineated crowns used to calculate the global performance ratio is the number of TP for the first evaluation approach and the number of matched cases for the second evaluation approach normalized by the total number of validation ITC.

4. RESULTS

The application of the method on Bernadouze forest provides global performance of 63% in position of trees (Table 1). It is 15% higher than the performance of the reference watershed segmentation. The decrease of false positive cases is directly linked to the decrease of over-segmented cases in recovery of crown evaluation (Table 2). For this second validation approach, global performance of the proposed method reaches 67% and is 17% higher than the performance of the reference watershed segmentation (Table 2). The number of over-segmented cases is reduced to 10 with the proposed method. The over-segmented cases correspond mostly of crowns larger than the mean crown radius of the forest. Our method shows some limitations to correct under-segmentation (under-segmentation cases correspond to 30% of the total validation ITC). These cases correspond mostly of crowns having an important overlap with their neighbors (mainly crowns located in the hearth of the forest). Isolated crowns are in majority correctly matched with the reference watershed segmentation and the proposed method.

Table 1: Delineation performance on the Bernadouze forest with tree position criteria (values are in number of crowns expect for performance)

	TP	FN	FP	Performance (%)
Only watershed	26	1	27	48%
Criteria application	34	1	19	63%

Table 2: Delineation performance on the Bernadouze forest with crowns recovery criteria (values are in number of crowns expect for performance)

	Matched	Missed	Over-segmented	Under-segmented	Performance (%)
Only watershed	27	0	12	15	50%
Criteria application	36	0	2	16	67%

5. DISCUSSION

The complexity of deciduous forest (broadleaf trees, steep relief, natural forest…) is a challenge for delineation. The simple application of a classical watershed method is limited. Our method is effective to correct over-segmentation by taking into account simultaneously structural and spectral features. However, in a case of high heterogeneity of crown shapes, delineation results show a large number of under-segmented delineation segments. The graph method is unable to divide existing segments into smaller ones. The proposed method has the advantage of being scalable and flexible by the addition of new criteria calculated on CHM or spectral data.

6. CONCLUSION

In this work, a graph based method to improve delineation results from classical watershed segmentation by using structural and spectral criteria has been presented. This method has been applied on a complex forest site with one dominant broadleaf tree specie, large crown overlap and steep relief. Our method significantly improves delineation results compare to a classical watershed segmentation method. However, some under-segmentation cases remain. This paper present preliminary results. In the next future, the proposed method will be applied on various forest sites with different characteristics (number of species, crown overlap, relief…) and larger validation dataset in order to evaluate its adaptability and robustness. Moreover, utilization of spectral indices will be evaluated in order to replace RGB bands for calculation of the spectral criterion

8. REFERENCES

[1] Lu, D., & Weng, Q. (2007). A survey of image classification methods and techniques for improving classification performance. International journal of Remote sensing, 28(5), 823-870.

[2] Kankare, V., Liang, X., Vastaranta, M., Yu, X., Holopainen, M., & Hyyppä, J. (2015). Diameter distribution estimation with laser scanning based multisource single tree inventory. ISPRS Journal of Photogrammetry and Remote Sensing, 108, 161-171.

[3] Bokusheva, R., Kogan, F., Vitkovskaya, I., Conradt, S., & Batyrbayeva, M. (2016). Satellite-based vegetation health indices as a criteria for insuring against drought-related yield losses. Agricultural and Forest Meteorology, 220, 200-206.

[4] Eva, H., Carboni, S., Achard, F., Stach, N., Durieux, L., Faure, J. F., & Mollicone, D. (2010). Monitoring forest areas from continental to territorial levels using a sample of medium spatial resolution satellite imagery. ISPRS Journal of Photogrammetry and Remote Sensing, 65(2), 191-197.

[5] Lindberg, E., & Holmgren, J. (2017). Individual tree crown methods for 3D data from remote sensing. Current forestry reports, 3(1), 19-31.

[6] Zhen, Z., Quackenbush, L. J., & Zhang, L. (2016). Trends in automatic individual tree crown detection and delineation?Evolution of LiDAR data. Remote Sensing, 8(4), 333.

[7] Barnes, C., Balzter, H., Barrett, K., Eddy, J., Milner, S., & Suárez, J. C. (2017). Individual tree crown delineation from airborne laser scanning for diseased larch forest stands. Remote Sensing, 9(3), 231.

[8] Jaafar, W. M., Shafrina, W., Woodhouse, I. H., Silva, C. A., Omar, H., Maulud, A., ... & Mohan, M. (2018). Improving Individual Tree Crown Delineation and Attributes Estimation of Tropical Forests Using Airborne LiDAR Data. Forests, 9(12), 759.

[9] Xiao, W., Zaforemska, A., Smigaj, M., Wang, Y., & Gaulton, R. (2019). Mean shift segmentation assessment for individual forest tree delineation from airborne LiDAR data. Remote Sensing, 11(11), 1263.

[10] Hu, X., Chen, W., & Xu, W. (2017). Adaptive Mean Shift-Based Identification of Individual Trees Using Airborne LiDAR Data. Remote Sensing, 9(2), 148.

[11] Strîmbu, V. F., & Strîmbu, B. M. (2015). A graph-based segmentation algorithm for tree crown extraction using airborne LiDAR data. ISPRS Journal of Photogrammetry and Remote Sensing, 104, 30-43.

[12] Hanapi, S. S., Shukor, S. A. A., & Johari, J. (2019, November). A Review on Remote Sensing-based Method for Tree Detection and Delineation. In IOP Conference Series: Materials Science and Engineering (Vol. 705, No. 1, p. 012024). IOP Publishing.

[13] Dalponte, M., Reyes, F., Kandare, K., & Gianelle, D. (2015). Delineation of individual tree crowns from ALS and hyperspectral data: a comparison among four methods. European Journal of Remote Sensing, 48(1), 365-382.

[14] Hastings, J. H., Ollinger, S. V., Ouimette, A. P., Sanders-DeMott, R., Palace, M. W., Ducey, M. J., ... & Orwig, D. A. (2020). Tree Species Traits Determine the Success of LiDAR-Based Crown Mapping in a Mixed Temperate Forest. Remote Sensing, 12(2), 309.

[15] Qiu, L., Jing, L., Hu, B., Li, H., & Tang, Y. (2020). A New Individual Tree Crown Delineation Method for High Resolution Multispectral Imagery. Remote Sensing, 12(3), 585.

[16] Poutier, L., Miesch, C., Lenot, X., Achard, V., & Boucher, Y. (2002, March). COMANCHE and COCHISE: two reciprocal atmospheric codes for hyperspectral remote sensing. In 2002 AVIRIS Earth Science and Applications Workshop Proceedings (pp. 1059-0889).

[17] Erudel (2018) Caractérisation de la biodiversité végétale et des impacts anthropiques en milieu montagneux par télédétection: apport des données aéroportées à très haute résolution spatiale et spectrale, thèse en collaboration Onera-Geode, cadre Labex DRIIHM

[18] Tochon, G., Féret, J. B., Valero, S., Martin, R. E., Tupayachi, R., Chanussot, J., ... & Asner, G. P. (2013). Segmentation hyperspectrale de forets tropicales par arbres de partition binaires. Revue française de photogrammétrie et de télédétection, (202), 55-65.