A benchmark of single tree detection methods using data from alpine forests

Lothar Eysn[1], Jean-Matthieu Monnet[2] and Markus Hollaus[1]

[1]*Vienna University of Technology, Department of Geodesy and Geoinformation, Research Group Photogrammetry, Gußhausstraße 27-29, A-1040 Vienna, Austria*
(Lothar.Eysn, Markus.Hollaus@geo.tuwien.ac.at)
[2]*Irstea, UR EMGR Écosystèmes Montagnards, centre de Grenoble, F-38402 Saint-Martin-d'Hères, France*
(jean-matthieu.monnet@irstea.fr)

Highlights: This study presents a new open-access dataset of 18 plots from alpine forests of the Alpine Space. Eight detection algorithms were tested and evaluated against forest inventory data using a novel, automated matching procedure. Forest structure remains a key issue limiting tree detection, and algorithms would probably benefit from an adaptive tuning in order to achieve a better trade-off between omission and commission errors.

Key words: *Tree extraction, comparative testing, mountain forest.*

Introduction

Area-based methods provide statistically calibrated maps of forest stand parameters such as growing stock, stem density and stand height, and are used for large-area forest inventory (FI) and long term forest management planning. Meanwhile, in complex alpine forests, single tree information is highly valuable. The spatial distribution of trees and their characteristics are important inputs for silviculture in uneven-aged stands, for growth simulation models or for the evaluation of the forest protection effect against rockfalls.

Numerous tree detection methods have been published in the literature, but benchmarks, i.e. comparison of different methods' performance on various forest stands are scarce. A study of Kaartinen, *et al.* [1] is mainly focused on Scandinavian forests and Vauhkonen, *et al.* [2] used very different forest types. The comparison of different algorithms and their evaluation on various forest types remain difficult, partly because of the absence of an open-access dataset with both, the airborne laser scanning (ALS) data and corresponding FI data. During the NEWFOR project, funded by the European Territorial Cooperation, a dataset of 18 mountain forest plots from 8 areas in 5 countries was constituted. Eight single tree detection algorithms were tested and evaluated with a novel, automated matching method [3]. The method uses a restricted nearest neighbouring approach to automatically link the detection results to the ground truth FI data. This article has three objectives. First, to present the dataset, which is now publicly available [4]. Second, to present the automated evaluation method, and third, to present the benchmark results.

Material and methods

Dataset

The ALS dataset is constituted of eight different surveys. It is somehow representative of the currently available operational data within the alpine countries. Data are heterogeneous as they originate from different sources, who acquired the data for different purposes. Point densities range from 5 to 121 m^{-2}, and four different types of scanners are used. Within these eight surveys, 18 forest plots are available, with stem locations, diameters, heights and species. The total surveyed area is 4.5 ha. Basal area among the plots ranges from 15.5 to 68.1 $m^2.ha^{-1}$, and mean height from 13.7 to 36.7 m. Coniferous proportion is between 23 and 100%. The plots were classified in four forest types: Single-Layered Mixed forest (SL/M, 4), Single-Layered Coniferous forest (SL/C, 5), Multi-Layered Mixed forest (ML/M, 7) and Multi-Layered Coniferous forest (ML/C, 2).

Detection algorithms

For each plot, the ALS data and rasterized terrain models at 0.5 and 1 m resolution were provided to benchmark participants. Participants applied their fully-automated tree detection algorithms in order to output a list with tree coordinates and heights for each plot. In total eight algorithms are tested. Most are based on local maxima (LM) detection using a rasterized canopy height model (CHM) and one relies on 3D point cloud processing. The LM-based methods use different approaches as for example filtering approaches, region growing, usage of multiple derived CHMs in different height layers, watersheds or polynomial fitting. Different settings as for example kernel size or spatial resolution of the input CHMs can be found. The method which is based on the 3D point cloud uses a segmentation and ellipsoidal clustering approach. The methods are applied to the data without any additional knowledge about the local forest (i.e. species composition).

Performance assessment

The evaluation of the detection results is carried out in a reproducible way by automatically matching them to precise in-situ FI data using a restricted nearest neighbouring approach. The matching algorithm is implemented in the OPALS forestry package [5]. Starting from the highest detected tree the restricted nearest neighbouring reference trees within a defined neighbourhood are detected. Restricted nearest neighbouring means that there are height and neighbourhood criterions which need to be fulfilled to match two trees. Finally, trees with the best neighbourhood and height vote are assigned. Only trees inside an area of interest are considered within the matching to overcome possible detection limitations at the borders of the input ALS data.

Based on the matching procedure, quantitative statistical parameters such as percentages of correctly matched trees and omission and commission errors are derived and presented in graphical representations. The benchmarking results are prepared in different levels of information, starting with investigations based on the method and forest type. Additionally an overall performance of the benchmark is evaluated.

Results and discussion

Evaluation of the matching procedure

A random sample of 699 detected trees was manually interpreted to test the developed matching algorithm. Only 3% were wrongly treated by the matching procedure. The overall accuracy is 97% with a Kappa of 0.94. This procedure enables interpreter-independent and reproducible results in short amount of time. Thus, it is an appropriate way to efficiently compare the detection results of several algorithms and for several test plots.

Detection performance

The vertical structure of the forest has a major impact on the detection results of the different methods (Figure 1). Trees in the lower layers are difficult to detect, even for point cloud-based methods, which results in lower assignment rates in the multi-layered stands. Mixed stands are also more troublesome: more complex crowns in deciduous trees are probably the reason for the higher commission rates. The best matching rate was obtained for single-layered coniferous forests. Dominated trees were challenging for all methods. In general, the tree detection rates show a higher variation than estimated tree heights. The overall performance shows a matching rate of 47%, which is comparable to results of other benchmarks performed in the past [1-2].

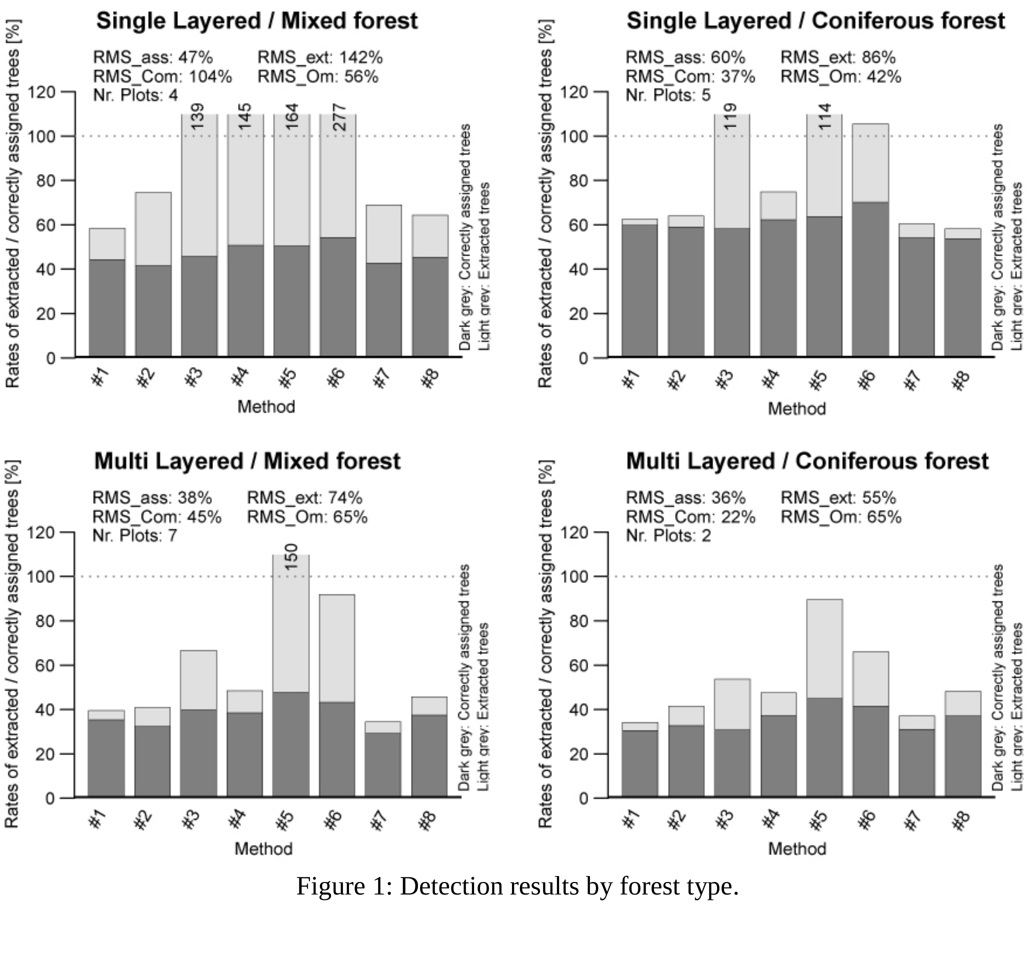

Figure 1: Detection results by forest type.

A method based on local maxima detection within a canopy height model using variable-sized moving windows is rated as the best performing algorithm. A point cloud clustering-based method gained the best results for trees in subdominant layers which is rated as advantage over raster-based methods.

The trade-off between omission and commission errors turns out to be a critical point regarding tree detection. Some methods are probably intrinsically more efficient, but algorithm parameters such as raster resolution, kernel size and horizontal vertical exclusion thresholds have a major impact on detection results. Depending on the forest structure and on the ALS acquisition parameters, the filters required for tree extraction have to be chosen or at least tuned specifically.

Conclusion

The study brings new insight regarding the potential and limits of tree detection with ALS and underlines some key aspects regarding the choice of method when performing single tree detection for the various forest types encountered in alpine regions. It turned out, that complex multi-layered forests are challenging for all tested methods. The best detection results could be obtained for single-layered coniferous forests. In order to improve the detection algorithm available for forest practitioners, it seems important to have datasets, that allow to test the robustness of algorithms on a wide range of forest structures and to design algorithms able to optimize their setting either based on internal (ALS data itself) or external data. Additionally a standardized matching procedure is needed for testing the algorithms in a clear and reproducible way. The presented matching methodology and the published dataset [4] should help to overcome this issue for future studies and applications.

References

[1] Kaartinen, H., Hyyppä, J., Yu, X., Vastaranta, M., Hyyppä, H., Kukko, A., Holopainen, M., Heipke, C., Hirschmugl, M., Morsdorf, F., Næsset, E., Pitkänen, J., Popescu, S., Solberg, S., Wolf, B.M. & Wu, J.-C. (2012). An international comparison of individual tree detection and extraction using airborne laser scanning. Remote Sensing, 4(4), 950-974.

[2] Vauhkonen, J., Ene, L., Gupta, S., Heinzel, J., Holmgren, J., Pitkänen, J., Solberg, S., Wang, Y., Weinacker, H., Hauglin, K.M., Lien, V., Packalén, P., Gobakken, T., Koch, B., Næsset, E., Tokola, T. & Maltamo, M. (2012). Comparative testing of single-tree detection algorithms under different types of forest. Forestry, 85, 27-40.

[3] Eysn, L., Hollaus, M., Lindberg, E., Berger, F., Monnet, J.-M., Dalponte, M., Kobal, M., Pellegrini, M., Lingua, E., Mongus, D. & Pfeifer, N. (2015). A benchmark of Lidar-based single tree detection methods using heterogeneous forest data from the Alpine Space. Forests, 6(5), 1721-1747.

[4] NEWFOR, The NEWFOR single tree detection benchmark dataset. http://www.newfor.net/download-newfor-single-tree-detection-benchmark-dataset/ (last access: March 2015).

[5] Pfeifer, N., Mandlburger, G., Otepka, J. & Karel, W. (2014). OPALS–A framework for airborne laser scanning data analysis. Computers, Environment and Urban Systems, 45, 125-136.