Application of Remote Sensing and GIS Methods for the Automatic Extraction of Single Trees Based on Digital Aerial Images and Elevation Models

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Abstract

The paper gives a short overview about the existing data base and extraction methods for single tree detection. Forest remote sensing has a long tradition and a variety of methods for single tree extraction have already been developed. Most studies and methods focus either on the analysis of satellite images or airborne laser data and on the extraction of coniferous trees. The automatic detection of deciduous trees is still a great challenge. This paper describes different methods of single tree extraction with focus on the automatic extraction of deciduous trees from aerial imagery. Single trees can be extracted by using aerial true-ortho images and photogrammetrically produced digital surface models as input data and a combination of remote sensing methods and GIS analyses with completeness and correctness over 80 percent. The presented method enables the extraction of tree tops as well as tree-crowns for deciduous trees. For the automatically extracted singles trees important attributes like exact position or average crown diameter are calculated and added to the tree objects. The extracted trees can be used for the modeling of trees in virtual environments or for forest area inventories.

Keywords: single tree detection, forest remote sensing, tree crown delineation, high spatial resolution data, semi global matching

1 Introduction

Remote Sensing has a very long tradition in forestry. Analogue and digital aerial images have been used for some decades for forest inventories. The main aims of forest remote sensing are the extraction of stock data and huge data inventories as well as the detection of forest damage, forest classifications and single tree detections. Because of photogrammetric and illumination effects and the mostly missing radiometric calibration of the camera an automatic classification of tree species based on multi spectral aerial images is not possible with high accuracy. Just a determination between coniferous trees and deciduous trees is possible. The main advantage of aerial images is the generation of a Digital Surface Model (DSM). This DSM is very helpful for the extraction of single trees.

First methods for automatic single tree detection were developed in the mid-1980s. The first approaches tried to identify single trees by the detection of local intensity maxima (Haenel et. al. 1987, Pinz 1988). With the improvement of the image resolution the significance of the geometry for the single tree detection increased (Fournier et. al. 1995). On account of the development of airborne laser scanner and the derivation of directly measured surface models many studies were published in which singles trees were extracted by surface models (Hyyppä et. al. 2001, Kaartinen & Hyyppä, 2008). According to Straub (2003) there is a distinguishing between a model driven approach and a data drive approach in the extraction of single trees. In the model driven approach (bottom-up) (picture 1) the 2D patterns based on a 3D model of a tree are generated via a geometric transformation into the image level. In this way the trees are detected through the execution of a pattern matching (Pollock 1994, Pollock 1996).

Picture 1: Model Driven Approach

(Source: Straub 2003)

The data driven approach (top-down) (picture 2) extracts in step one edges and regions (Persson et. al. 2002). In step two tree objects are generated grouping of these attributes.

Picture 2: Data Driven Approach

(Source: Straub 2003)

Due to the very high resolution and the ensuing high complexity of areal images the automatic extraction of single trees in a close tree population or in forest stands especially of deciduous trees is still a great challenge. *The main aim of this paper is the presentation of an easily reproducible approach for single tree detection based on high resolution aerial true-ortho images and digital surface models* .One further aim of the developed approach was adaptability for huge areas and for different aerial camera systems. Furthermore different tree attributes like the height of a tree have to be calculated and attributed to the automatically extracted tree object. The process is based on existing and common GIS and remote sensing software and algorithms, the top of the trees as well as and the crowns of the trees are extracted.

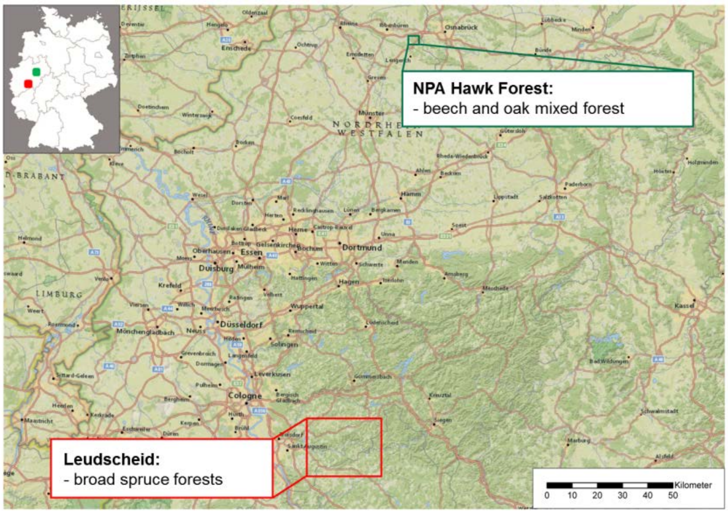
2 Data Sources and Investigation Areas

Most published methods use satellite images and airborne laser data as data source. The use of these data is already verified. Airborne laser data with a high resolution are very expensive and satellite images usually have either a low resolution or if the resolution is high are still very expensive. In addition the synchronous acquisition and availability is not given. The use of aerial images for the extraction of single trees is not common. Compared to airborne laser data the advantages of aerial imagery are a good availability, flexible data acquisition, the contemporary availability of imagery and photogrammetric DSM and the lower costs per km². This paper is focusing on high resolution aerial images and photogrammetric produced digital surface models.

2.1 Investigation Areas

For the development of the presented approach two investigation areas in North Rhine-Westphalia in Germany were selected (picture 3). Both regions are typical central-European forest areas. Investigation area one is the nature protection area (NPA) Habichtswald close to Osnabrück. This area is characterized by a high proportion of beech and oak mixed forest. There are also some small areas of alder and spruce forests. Investigation area two is the so called Leudscheid southwest of Cologne. This area is characterized by broad spruce forests.

Picture 3: Investigation Areas



(Map Source: ESRI Basemap)

For the development of a reproducible approach only standard aerial camera systems were used. In the area of the NPA Hawk Forest a DMC-1 picture flight with 80 % along and 40 % across track overlap was available. The flight day was the 2nd of May 2011. In the Leudscheid area an UltraCam XP picture flight with an overlap of 80 % / 30 % was used, image acquisition was on the 22nd of September 2010. The used x-y-resolution in both investigation areas was 20 centimeter and the z-resolution was 10 centimeter. The ability of the data source for forest applications was already demonstrated in a previously published study (Miri et. al. 2013).

2.2 Generation of Digital Surface Model (DSM) and True Ortho Mosaic (TOM)

A processing chain for automatically creating high resolution Digital Surface Models (DSM) from aerial and satellite images has been developed at the Institute of Robotics and Mechatronics of the German Aerospace Center (DLR). The processing chain is based on the Semi-Global Matching (SGM) method (Hirschmüller, 2005 &2008), it has been implemented in a Linux computer cluster. The cameras data processed include aerial push broom systems like HRSC developed by the DLR Institute of Planetary Research and the ADS 40. Within the past few years, these methods have been extensively applied to many datasets of commercial full frame cameras like UltraCam-D, -X and -Xp or DMC-1/-2. Finally, SGM has also been applied to images from commercial satellites, like Quickbird and World View for creating DSMs with 0.5 m/pixel.

Using the Semi Global Matching (SGM) algorithm a detailed DSM in full image resolution can be generated. SGM is a pixel-sharp dense matching algorithm currently accepted to set the worldwide standard for photogrammetric image matching.

Traditional orthophotos are generated by the projection of the oriented images on a Digital Terrain Model (DTM). Elevated objects (like houses and trees), which are included in a DSM, are not represented in a DTM, therefore projective effects are prominent (e.g. house facades are visible) and the geometry of elevated objects is not correct. For a TOM a DSM is used, therefore the geometry of the elevated objects is correct if an ideal DSM is used.

Visually orthophotos may give a sharper impression; errors in a pixel sharp DSM especially along borders of elevated objects produce errors in a TOM. Nevertheless for mapping and classification the combination of TOM and DSM is by far better suited than a traditional orthophoto since they are geometrically correct and perfectly co-registered (picture 4).

Picture 4: Orthophoto and True Orthophoto Mosaic

2.3 Generation of Digital Terrain Model (DTM) and normalized Digital Surface Model (nDSM)

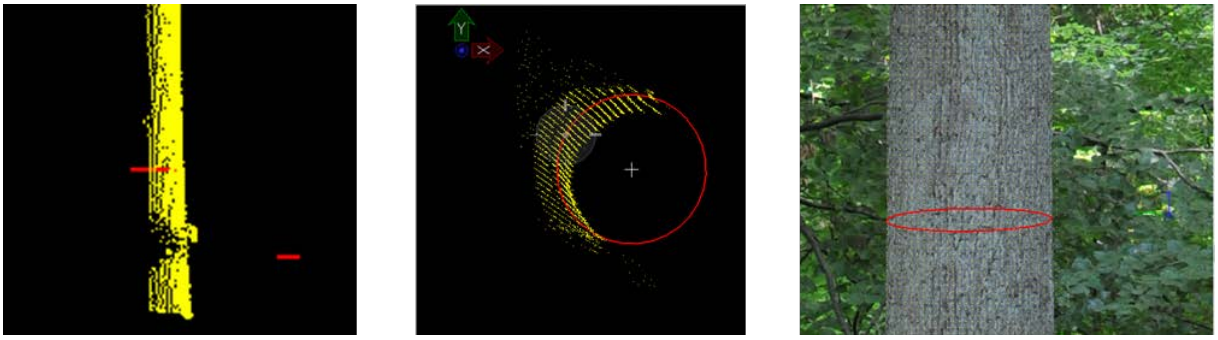
The generation of a normalized digital surface model is not necessary for the extraction of single tree objects. But the nDSM is sine qua non for the calculation of tree attributes. For the generation of a DTM and a nDSM the photogrammetric data is used as input. To subdivide the DSM into ground- and elevated pixel a fully automated modification of the method described in Mayer (2000) was used. Matching algorithms like SGM may produce erroneous matchings and artifacts in a DSM e.g. caused by homogenous surfaces or surfaces with repetitive textures. As the DTM-generation method uses filter windows sensitive to such noise, a preprocessing was done on the DSM in which small negative outliers were removed from the DSM using a one-sided median filter that fills gaps in the surface. Once the subdivision of the DSM into surface and elevates object-pixels was done, a DTM was generated by cutting and interpolating all elevated pixels using the surrounding ground pixels with an inverse distance weighting function. Subtracting the DTM from the DSM resulted in normalized DSM (nDSM) containing only heights above the ground.

In very densely wooded areas with no visible ground marks on bare earth and simultaneously steep terrain the photogrammetric generation of DTM has its limits. In mountain areas it is helpful to use a low resolution laser DTM. This data can be investigated easily and cost-efficient. Because of low soil erosion in forest areas it is sufficient to investigate this data every 20 or 30 years. In Germany this data is provided by the land surveying offices.

2.4 Control data

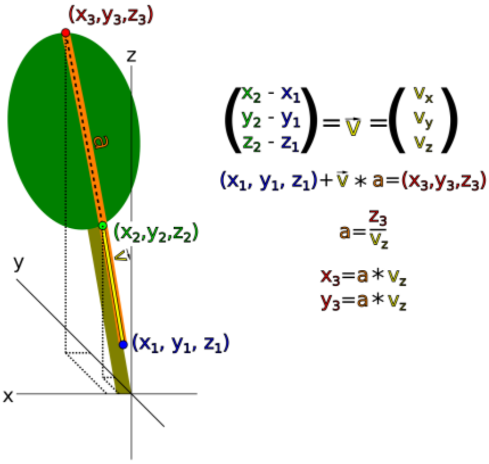
To calculate the completeness and the correctness of the extraction results 524 deciduous control trees and 92 coniferous control trees were measured with a terrestrial Riegl Laser Scanner LMS Z620. The local accuracy of this control points is better than 6mm. The global accuracy of this control points is better than 5mm based on geodetic reference points. After the terrestrial measurement the control trees were determined with an accuracy of one centimeter with the software PHIDIAS in MicroStation. All trees which were visible within the terrestrial laser point cloud and in the accompanying photo were collected (picture 5).

Picture 5: Control Data



On every tree trunk two points were measured. The first measurement aimed for the diameter at breast height (DBH), the second measurement point was the highest possible visible mark in the point cloud and the photo. This enables the calculation of the trunk inclination and a better calculation of the control point at the crown level (picture 6).

Picture 6: Control Tree Measurement



(Concept and Layout: Eric Rose, FU Berlin)

In order to calculate the completeness and the correctness of coniferous trees only trees with a DBH of 15 centimeters and more are used as control trees, in deciduous forest just trees with a DBH of 20 centimeters and more. Trees with a lower DBH are not used as control trees; they can be used for the calculation of the understory of the tree population.

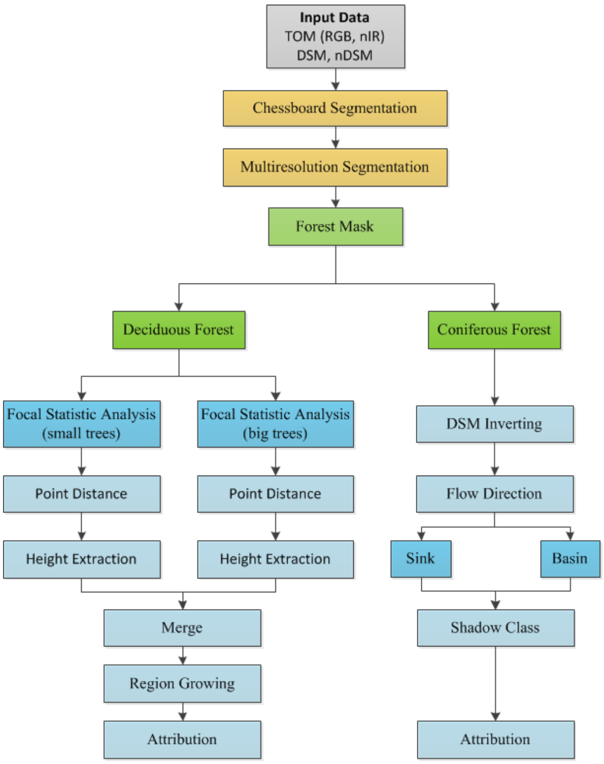
To expand the control point data base and to improve the accuracy assessment 500 additional control trees were manually digitized in coniferous forest using the TOM.

3 Methodology

Basis for the extraction of trees based on aerial images is the morphological definition of a tree. In this paper a tree is defined by a minimum crown area of 3 $m^2$and a minimum tree height of 3 m. A tree is also characterized by a high NDVI value. Other attributes like the tree trunk cannot be used to define a tree because of the constraints of the used data source.

Basis for the presented approach is an object-based image segmentation conducted in the commercial software Trimble eCognition 8 (picture 7). In order to distinguish between elevated and flat vegetation a forest mask was calculated. Due to the different morphology of deciduous and coniferous trees and the strong influence of the tree morphology on the extraction strategy the forest class was divided into a deciduous forest class and a coniferous forest class. These classes are the basis for single tree extraction. To reduce the calculating time and to improve the results only the areas inside the forest classes are used for the execution of single tree detection.

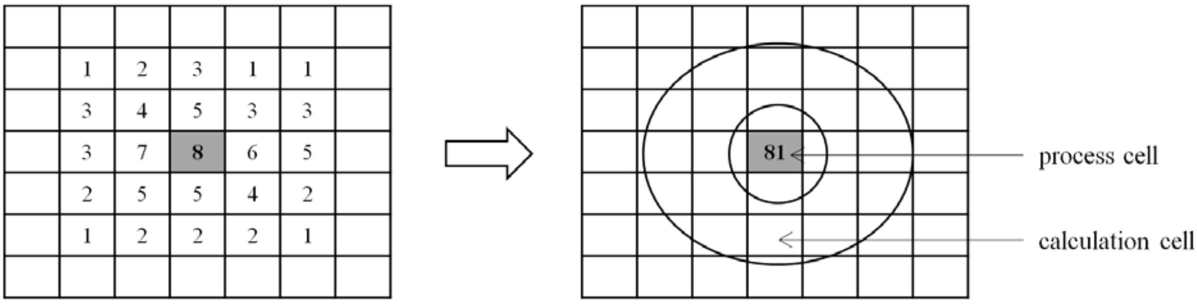
Picture 7: Workflow



3.1 Focal Statistics Analysis and Region Growing

The GIS-based focal statistics analysis is an implementation of a neighborhood operation with a maximum function within a default detection raster for tree tops in a nDSM. The detection raster is based on an annular shape which applies only values between the inner and the outer circle. The output value is in this case a function of the adjacent input cells; that means the sum of all values in the neighborhood of the local maximum are added and output (ESRI 2012) (picture 8). This fact allows the detection of different kinds and heights of trees through the modification of the annular shape's size and the change of the proportion between the inner and outer circle (Poznanska et. al. 2013).

Picture 8: Focal Statistics Analysis



(Source: picture modified after ESRI 2012)

If the tree population in the investigation area is characterized by different tree heights and sizes and a high diversity of trees it is helpful to use two or three parallel focal statistic loops (picture 7). This means, that small and big trees can be detected with different focal statistics analyses. Within the focal statistics analysis, a point distance analysis is implemented to eliminate possibly mistaken multiple tree tops. If two or more focal statistics analysis loops are necessary it is helpful to implement a height extraction within the GIS analysis. For example in the analysis path for the small trees just tree tops with a height up to 10m are

detected and in the analysis path for the big trees just tree tops with a height from 10m are detected. At the end of the focal statistics analysis the different classes of tree tops are merged into one class.
In order to extract the crowns of trees a region growing segmentation (Schiewe 2002) is implemented because it is the most suitable method for crown detection. Basis for the region growing algorithm are the extracted tree tops. The tree tops are the starting cell of the segmentation process. Based on the top of trees the crown segments grow because of the consideration of the geometric and radiometric information as well as statistical tree proportions and neighborhood classes.
After the extraction of tree tops and crowns the maximum tree height, the exact tree position, the average crown diameter and the crown area are calculated and attributed to the extracted tree segments.

3.2 GIS-based Sink and Basin Analysis

In coniferous forests a GIS-based sink and basin analysis (picture 7) also leads to good results. The sink and basin analysis starts with an inversion of the DSM or the nDSM. Based on the inverted surface model the flow direction of every cell to its neighborhood cell with the highest slope is calculated with a hydrological algorithm. The inverted surface model is flooded and the drainage basins are calculated. By means of an intersection with a shadow class the crowns of the coniferous trees can be defined with a very high accuracy. This means that only in the TOM visible parts of the trees are used for the crown delineation. Because of the tree shadow not visible parts of the trees are classified as a shadow class. This method is similar to the watershed transformation but leads to better results.
Based on calculated flow direction and with the flooded surface model the tree tops can be extracted with a sink analysis. “A sink is a cell or set of spatially connected cells whose flow direction cannot be assigned one of the eight valid values in a flow direction raster” (Esri 2013). The basin and sink analysis can also be carried out with the RGB or the nIR Layer (Bayer at. el. 2013).

4 Results and Accuracy

To evaluate the accuracy of the results the completeness and the correctness according to Straub (2003) was calculated.

The completeness (com.) of the results is calculated as follows:

$$\text{completeness (\%)} = \frac{\text{correctly extracted trees}}{\text{correctly extracted trees } + \text{not extracted trees}} * 100$$

The correctness (cor.) of the results is calculated as follows:

$$\text{correctness (\%)} = \frac{\text{correctly extracted trees}}{\text{correctly extracted trees } + \text{wrong extracted trees}} * 100$$

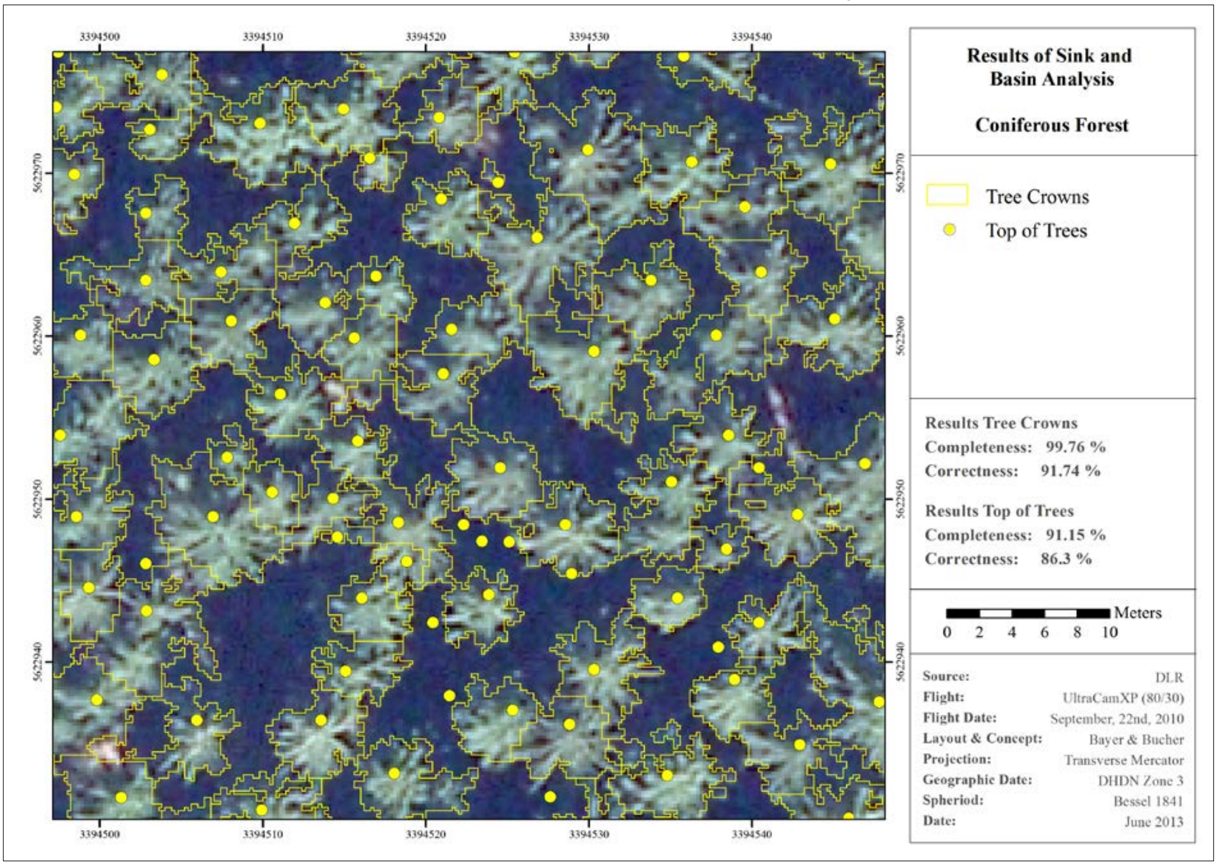
4.1 Results and Accuracy in Coniferous Forest

The focal statistics analysis and the region growing algorithm lead to the best results in coniferous forest. Nevertheless the sink and basin analysis deliver good results too. It is a fast and easy reproducible GIS method for the extraction of coniferous trees.
To determine the accuracy of the tree tops all automatic extracted trees with a maximum distance of 2.5 meter to the control trees were determined as right extracted trees. The completeness of the sink analysis is 91.15 percent. The correctness of the extracted tree tops is 86.3 percent. In comparison to the focal statistics analyses the position accuracy is slightly behind. The sink analysis also lead to an insignificantly over determination of tree tops. The completeness of the tree crown detection with the basin analysis is over 99 percent. Almost all

trees can be detected with this analysis in coniferous forests. The correctness of the extracted tree crowns is 91.74 percent (picture 9).

The accuracy of the sink and basin analysis is depending on the resolution of the DSM or nDSM. By using the original resolution of 20 centimeter both methods lead to a detection of minor maxima and an over determination. The best results deliver a resolution of 50 centimeter.

Picture 9: Results of Basin and Sink Analysis



4.2 Results and Accuracy in Deciduous Forest

Due to the deciduous tree morphology with broader crowns a maximum distance of 5 meters between the control trees and the extracted trees was assumed for the calculation of the correctly extracted trees. The completeness of the extracted deciduous trees is 87.75 percent. The correctness of the tree tops is 88.8 percent (picture 10). The correctness of the crowns could not be calculated because there was no control crown layer accessible. The accuracy of the focal statistics analysis is also depending on the resolution of the DSM. A resolution between 40 and 50 centimeter delivers the best completeness and correctness.

Picture 10: Results of Focal Statistics Analysis and Region Growing Segmentation

5 Conclusion

Based on a TOM and a DSM coniferous trees can be extracted with a high completeness and correctness of over 90 percent. Only the understory in coniferous forest cannot be extracted because of constrains of the used data source. Also deciduous trees can be extracted with a high accuracy of over 85 percent. Unpaired deciduous trees can be extracted almost completely. Trees in a tree population with a diverse age and size structure can be extracted with a high accuracy. Trees within a monostructured tree population with a same size and height cannot be extracted very well and also trees with a branch tree trunk cannot be extracted as a single tree because of the central perspective of the TOM. Furthermore big bushes and small trees cannot be distinguished.

The detected trees and the calculated tree attributes are important for forest administrations and forest enterprises. The extraction results can be used for forest inventories, harvest planning and change detections analyses after damaging events like forest fire or storm losses. The developed approach also provides a new input to improve the extraction accuracy of single trees on a large scale level and illustrates the opportunities for the detection of deciduous trees, which is still a challenge in science today. The extracted tree objects and their attributes are also helpful for the modeling of trees in virtual environments.

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