INDIVIDUAL TREE CROWNS DELINEATION USING LOCAL MAXIMA APPROACH AND SEEDED REGION GROWING TECHNIQUE

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Abstract

Remote sensing applications in forestry can profit from a rapid development of optical sensors. New hyperspectral sensors have very high spatial and spectral resolution and provide continuous spectral cover in visible and infrared spectral region. Applied algorithms should be suited to the new properties of the data to achieve its maximal advantage.

Segmentation of the image into objects is a fundamental task in image processing. It is important in forestry applications of optical remote sensing as well. We are looking for a position of individual tree crowns. Such process traditionally involves two parts — 1) detection and 2) delineation phase. Local maxima approach and seeded region growing technique are presented as the key concepts. Furthermore improvements, namely histogram equalization and Voronoi diagram, are incorporated.

Two independent datasets were processed and results of the segmentation are presented. Hyperspectral data with spatial resolution of 0.8m were found as a suitable for segmentation process with 84% and 78% accuracy of detection phase and 64% and 52% accuracy in delineation phase respectively. Finally discussion of recommended settings in the algorithm is provided based on the segmentation results.

Keywords:

Optical remote sensing, individual tree crowns, local maxima detection, seeded region growing

INTRODUCTION

Remote sensing is a science field with a rapid development, especially when speaking about the spatial and spectral resolution. Satellite sensors with a few spectral bands (multispectral) and pixel sizes ranging from tens of meters to kilometers, are in use since 1970'. Data provided by such sensors are used for global monitoring, i.e. in weather forecast. New hyperspectral sensors (especially airborne ones) provide a data with a distinctively higher spatial and spectral resolution. Spatial resolution with a pixel size in centimeters and hundreds of narrow spectral bands within a wide range of electromagnetic spectrum are common (Goetz, 2009). This improvement in hardware implies development of appropriate software - algorithms must be suited to the data. (Gougeon et al., 2006)

In forestry remote sensing went through a long way as a tool for forest health monitoring, global biomass distribution analysis etc. New hyperspectral sensors with very high spectral resolution and continuous spectral cover provide more precise estimates of qualitative and even quantitative biophysical and biochemical parameters. (Asner, 1998, Ustin et al., 2009, Rautiainen et al., 2010)

A fundamental task of image processing — image segmentation — is important in remote sensing too. Segmentation of an image into individual objects for foresters' purposes means segmentation of individual tree crowns. Tree crown is an area with a relatively high reflectance (e.g. in NIR spectral region) compared to neighboring area. Therefore the crowns can be found around a local maximum of brightness. Successful detection of a tree crown position as well as delineation of a whole tree crown area depends on several conditions. Specific tree species, age and height, stand density must be taken into consideration as well as variation in these parameters across the region of interest. Secondly, the radiometric, spatial and spectral resolution of the sensor differs for specific sensor-tree-sun geometry present during data acquisition and therefore must be treated as well.

In this paper we present the evaluation of a modified crown segmentation algorithm on hyperspectral data with spatial resolution better than 1 meter and spectral resolution lower than 20nm.

MATERIAL

Study sites

We tested the segmentation algorithms on several data sets acquired over Šumava Mts. with airborne hyperspectral and spectrozonal sensors, Study site “Černá Hora” (48.59N; 13.35E; mean elevation of 1200 m.a.s.l.) was selected for our purposes. The dominant tree species is a mature Norway spruce (Picea Abies, L. Karst) influenced by various stressors (e.g. massive wind-fall after hurricane “Kirril” or bark beetle outbreak), thus we expected different health conditions of trees within the area. However, the canopies were still relatively closed (canopy cover about 80 %). The data used in this study were acquired during a flight campaigns in September 2009 and July 2010.

Remote sensing data

Two different datasets were used for the purposes of the study. First, the airborne hyperspectral data of AISA Dual system (Specim, Finland) were collected over the site on 1st September 2009. AISA Dual is a combination of VNIR Eagle (Hanuš et al., 2008) and SWIR Hawk sensors, with capabilities to acquire the data in spectral range from 400nm to 2500nm with maximal spatial resolution of 0.8m and full-width-half maximum (FWHM) of 12nm. This configuration was used in our study. Acquired image lines were georeferenced using the IMU/GPS navigation data, converted from raw DN values into at-sensor radiance (using sensor-specific calibration files) and further converted into real reflectance values using ATCOR-4 atmospheric correction module (ReSe, UZH, Switzerland). Such radiometrically and geometrically corrected data were used as an algorithm inputs.

Secondly, large format digital spectrozonal camera UltraCamX data were acquired on 7th July 2010. The camera produces images in high resolution of 136 Mpix (spatial resolution up to 0.2m) with RGB, Grayscale or CIR outputs. These data were used for validation of crowns identification / delineation performed on hyperspectral datasets.

METHODS

Segmentation process traditionally involves two main parts: 1) tree crowns detection and 2) tree crowns delineation. Several approaches are possible for both tasks. We tested the most suitable procedures for our data. In this paper we present a segmentation process based on broadly used approaches with several improvements.

In case of crowns detection, we applied a local maxima approach with variable window size for a detection of different crown size combined with adaptive equalization for highlighting of shaded crown parts. For tree crowns delineation we applied a seeded region growing technique with Voronoi diagrams used as primary mesh and several stopping conditions enabled.

From data to image

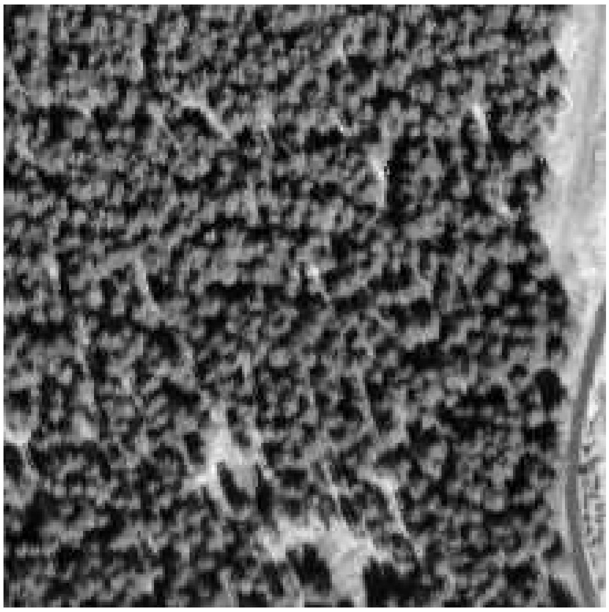
From the nature of hyperspectral data, we have information about reflectance in hundreds of spectral bands. This can be useful for detailed spectral analyses but tree crown detection and delineation is a question of texture and structure rather than its spectral features.

The input of a segmentation algorithm is an average brightness image computed from original data. Averaging can be performed over all available bands. That is convenient for multispectral data with several spectral bands. However, when using hyperspectral data with many narrow bands, such approach would lead to the loss of specific spectral characteristic of vegetation. We selected several wavelengths, where spectral characteristic of vegetation plays a major role. Average brightness image is then computed over selected bands. (See Table 1, Figure 1.)

Table 1. Selected spectral bands

AISA Eagle, 65 bands		AISA Dual, 359 bands	
band n.	wavelength	band n.	wavelength
13	497.5 nm	24	502.2 nm
19	551.3 nm	35	551.7 nm
25	606.6 nm	48	612.1 nm
33	680.7 nm	63	681.8 nm
37	717.8 nm	71	719.1 nm
43	773.9 nm	82	770.9 nm
51	849.4 nm	99	851.8 nm

Figure 1. Average brightness image



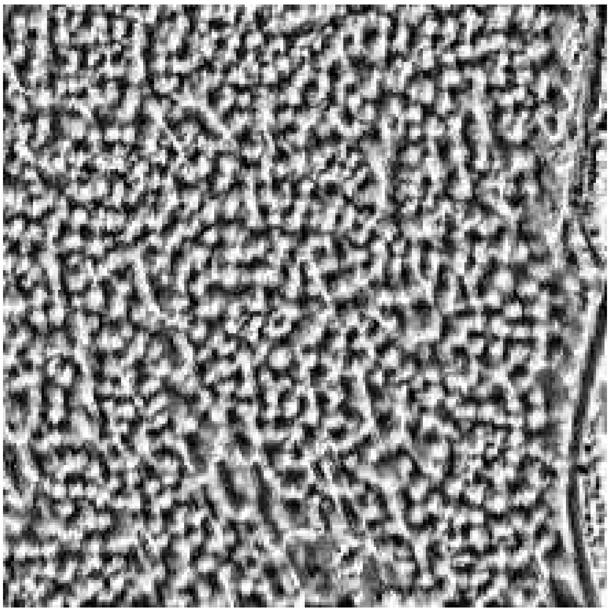
Adaptive equalization

When talking about the trees in average brightness image, we distinguish the individual tree crowns as brighter parts surrounded by shadows. Depending on actual sun angle, certain parts of the crowns are usually shaded. This would cause inaccuracy especially in delineation phase. Shaded parts can be effectively highlighted using adaptive equalization.

Histogram equalization is well-known technique used in image processing — its main goal is to provide a uniform distribution of pixel values. Adaptive approach applies a transformation on single pixel using cumulative histogram calculated from particular pixel neighborhood as transforming function. This procedure results in better contrast of the image, in our case shaded parts of the crowns are highlighted.

Average brightness image is saved as a 2D matrix of floating point numbers ranging between 0 and 1. For the equalization, we selected a specific number of subintervals between 0 and 1. Then we transformed pixel values in such way, that percent occurrence of pixel values from particular neighborhood in selected subintervals should be uniform.

Crucial input parameter of histogram equalization is the neighborhood size entering the calculations. It should correspond with the expected size of tree crowns; therefore it directly depends on a spatial resolution of processed data (see Figure 2). Moreover, crown sizes can vary significantly over regions of interest as well.



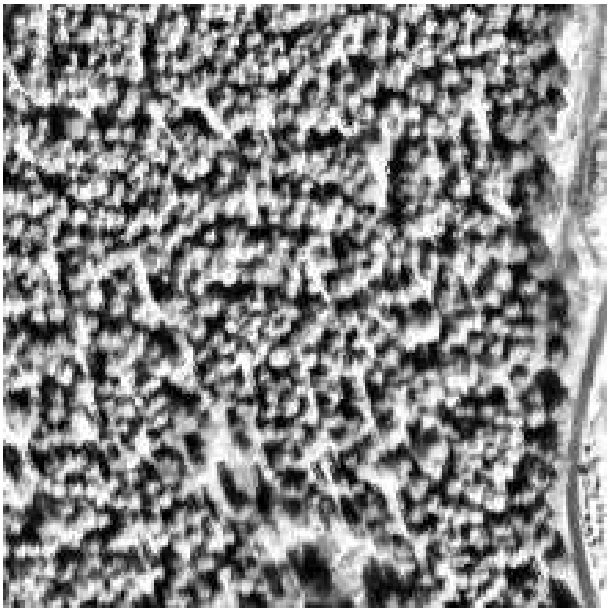


Figure 2. Equalized images, effects of different neighborhood sizes. The results obtained for region of interest using following set up: Pixel size is 80 cm, 100 subintervals were defined over the range from 0 to 1 and size of pixel neighborhood was 11 pixels for the left image and 31 pixels for the right image.

Using filters and masks

Average brightness image (both before and after equalization) holds structural information of higher as well as lower frequency. Higher frequency information represents in-crown details, understory structures and noise. Tree crowns and superior canopy structures are present in lower frequency information. While higher frequency information can be amplified by equalization, the lower frequency information is more important for segmentation process.

Therefore prior to the crown detection (with local maxima approach) use of some low-pass filter is advisable. Most common low-pass filters are so called Gaussian kernels, where again appropriate kernel size is a key factor. Example of results is shown in Figure 3.

There are also other structures inside the region of interest beyond the tree crowns itself. It is therefore advisable to exclude non-tree structures from the next steps of delineation process. Binary image mask can be applied on non-tree areas to find local maxima of sole tree crowns. Automatic supervised / unsupervised classification of the image can be applied, focusing mainly on exposed crown tops. Such mask is then applied before local maxima locating, local maxima found outside the tree tops are rejected.

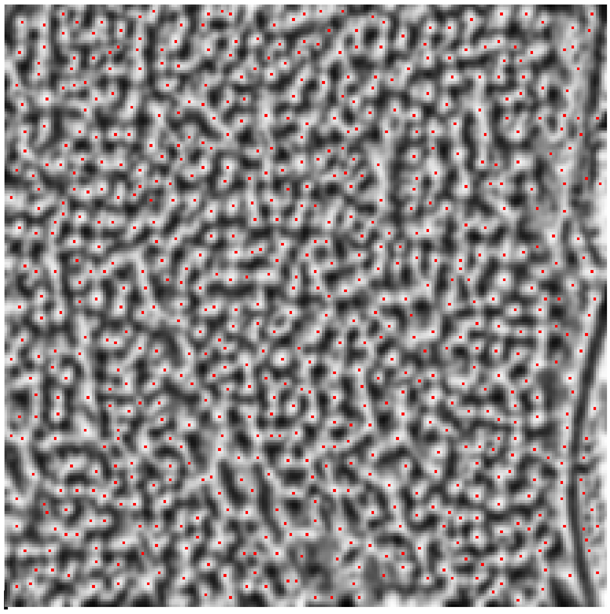


Figure 3. Filtered image with local maxima marked. Gaussian filter was used with kernel size 7 and sigma = 2

Identification of local maximal

In average brightness image the brightest pixels represent tree crown top points. However, the brightest point of the tree is not necessarily the crown top, while it depends on actual sun and sensor angle configuration too. Still, the local maxima approach works well for tree location estimates and local maxima are useful as seeds for tree crown delineation.

It is important to have only one local maxima found in each crown for following steps. We have to make a decision about each pixel, whether or not it could be a maximum inside some neighborhood. Size of this neighborhood should correspond to expected crown size, but crown sizes can vary significantly over the region of interest. The use of statistical and topological analysis of a pixel neighborhood can help us with decision about appropriate local-maxima-window size. Semivariograms calculated in eight directions from analyzed pixel tell us about pixel self-similarity against the neighborhood, while slope breaks searching for local minima in eight directions tell us about expected distances to the between-tree edge. (Wulder, 2000, [6]) These two values are then averaged to obtain a representative window size for local maxima check. (See Figure 3)

Seeded region growing

Seeded region growing is an iterative process started in a pixel from the set of seeds. Pixels from the seed neighborhood are subsequently classified whether or not they are part of the same crown as the seed. (Hirschmugl et al., 2007)

Many classification criteria are possible and useful to apply, such as:

1) Absolute distance from the seed. We set the limit according to an estimation of maximal tree crown size and classify a pixel as acceptable while its distance from the seed is within set distance limits.
2) Brightness agreement. Seed pixels are found as the brightest ones. Whole crown area should hold at least part of the brightness of the seed, but appropriate threshold have to be set up. A brightness of classified pixel can be compared with brightness of the seed or with brightness of all pixels assigned to the crown so far.
or 3) Spectral agreement - Whole spectrum (or some part) of the seed and the classified pixel can be compared. Appropriate threshold should be set up, according to comparison approach. This approach is especially suited to hyperspectral data. Possible applications are further described in [8].

The above mentioned criteria apply to individual tree crowns. However, the trees groups in a forest and therefore shares common forest area. The boundaries between the forests should be respected and somehow included. Starting from all the seeds simultaneously and growing the regions in equivalent steps is the first important approach. Meanwhile, it is useful to have some preliminary conception of forest area division. For this purpose, the Voronoi diagram based on a position of the seeds is build. Forest boundaries found by using these two approaches should not be crossed during the region growing process.

Final corrections can be made in the last phase of delineation process. Obviously incorrect classification of some pixels can be corrected or nullified and regions under some size threshold can be removed.

RESULTS AND DISCUSION

Rectangular region of interest with a side of 176 meters was selected in a Černá Hora site. Subsets of a data from three available datasets were made. Two datasets of the same area acquired within 1 month with spatial resolution of 80 cm were used as inputs to segmentation process. Image from RGB aerial digital camera with pixel size of 20 cm was used to manually validate the results.

Region of interest covers approximately 3 hectares of closed forest stand of Norway spruce. Most of the trees are mature individuals. (See Figure 4.)

In case of AISA Eagle campaign (Eagle), the region of interest is represented by a rectangular subset with a side of 220 pixels. We have 65 spectral bands available in a range from 400 to 1000 nm with a spatial resolution of 80 cm. In AISA Dual campaign (Dual) the region of interest is represented by a rectangular subset with a side of 220 pixels. We have 150 spectral bands available in range from 400 to 1150 nm with a spatial resolution of 80 cm.

Figure 4. RGB image of the region of interest, subset from digital camera data with 20 cm spatial resolution, exported from ENVI software

Average brightness image was computed using selected bands (see Table 1.). Adaptive equalization of brightness image was performed with 11 pixels size of a floating window and normalized brightness interval 0 to 1 divided into 100 classes. Filtration of the equalized image was done by a Gaussian kernel with size of 7 pixels. The supervised classification of the image was performed in ENVI software using a neural net with image classes of exposed tree crowns, shaded parts, grass fields and roads. Resulting mask (masking out everything but the exposed tree tops) was applied in segmentation software. Then, the local maxima detection was performed.

Table 2. Tree crown detection settings

Average brightness image	averaging over selected bands
Equalization kernel size	11 pixels
Equalization classes	100 classes over range from 0 to 1
Image filtering	Gaussian kernel, size 7 pixels, sigma = 2
Local maxima detection	variable window size

Tree crown detection results

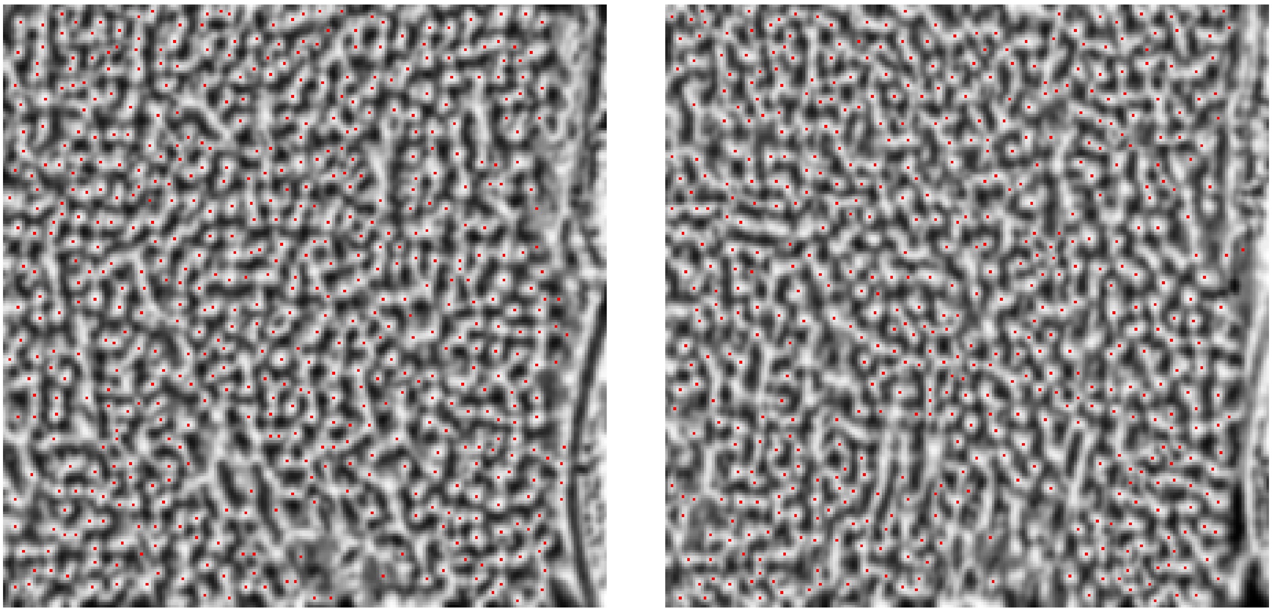


Figure 5. Local maxima = tree crown positions detected in the images (Eagle – left, Dual – right)

Identified local maxima were manually evaluated whether or not they fit to the actual tree positions. Very high spatial resolution image (pixel size 20 cm) acquired by UltraCamX was used as a reference about exact tree positions. Local maxima and tree positions were rated with the following three categories. A) If one local maximum stands for one tree crown we judge it as successful tree detection. B) If local maximum is found where no tree occurs, we judge it as incorrect tree detection. C) And if there is no local maximum found over a tree crown area we judge it as omitted tree detection.

We looked on the Eagle data first. In a rectangular region of interest of approximate size 176 x 68 meters (first 85 lines of the image above) 257 trees and 233 local maxima were located. It includes 223 successfully detected, 10 incorrectly detected and 34 omitted trees. That means nearly 84% efficiency of tree detection phase. For the Dual data we took the same part of the image, it covers nearly the same area. Again 257 trees and 213 local maxima were located, including 206 successfully detected, 7 incorrectly detected and 51 omitted trees. That means 78% efficiency of tree detection phase.

Numbers of both omitted and incorrectly detected trees depend on classification mask used. Without a mask more incorrect “trees” would be found in grass fields, roads, etc. On the other hand probably no trees would be omitted, aside from the problematic category. It is question of a coincidence (and a spatial resolution to be fair), whether or not two very closely standing trees would be distinguished.

Tree crown delineation phase was started with local maxima found in the first phase as the seeds. Seeded region growing was performed with the following initial settings. We expect maximal crown diameter of 12 meters, therefore with 80 cm pixel size maximal distance from seed is 7 pixels. Minimal agreement in brightness required was set to 40 percent compared to seed brightness value and 50 percent compared to the average of previously accepted crown pixels. Borders set up by a Voronoi diagram were modified three times and it was allowed to cross the border at most by two pixels. Foreign territories made by previously accepted pixels are not allowed to be crossed. Step by step in radial direction all seeds were developed simultaneously.

Table 3. Seeded region growing settings

Distance from seed	7 pixels
Brightness agreement with seed	40 %
Brightness agreement with average	50 %
Spectral agreement	not required
Voronoi boundaries	modified 3 times
Boundary crossing	at most 2 pixels

Tree crown delineation results

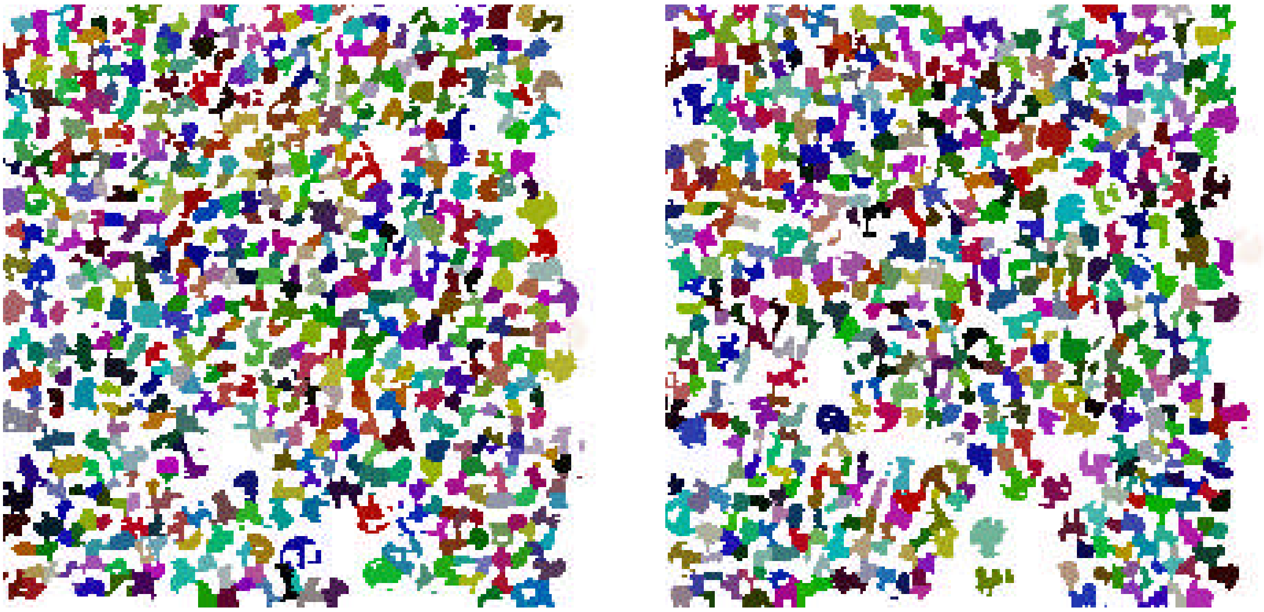


Figure 6. Results of seeded region growing (Eagle – left, Dual – right)

The results of a delineation phase were evaluated manually by direct comparison with very high spatial resolution image as well. Agreement between delineated crown area and actual tree crown was rated using scale from 0 to 4 with the following meaning. Rating 0 means 0% agreement or more precisely strong disagreement between a delineated area and a tree crown in size and shape. Very good agreement in size and shape, denoted as 100% agreement, is rated with 4.

We worked with the first 85 lines of the images again. For the Eagle data 230 delineated areas were evaluated with average 64% agreement, 90 areas rated 2 or less and 140 areas rated 3 or 4. For the Dual data 211 delineated areas were evaluated with average 52% agreement, 109 areas rated 2 or less, 102 areas rated 3 or 4.

We can see an agreement between tree crown detection and tree crown delineation results. More omitted trees in a detection phase on the Dual data implied worse segmentation results. It is understandable; typically when one of the two trees standing close to each other is not detected, the crown of the other is grown over both of them and would be rated as unsatisfactory. Improvements in both parts of algorithm are important and should be done to achieve better results.

There were minor differences between Eagle and Dual campaign, for example slightly in possition and geometry of the flight operating lines or in the post processing corrections (especially geometric ones). The differences in the results after the same segmentation process are expectable. On the other hand in both cases the applicability of 80cm optical data for tree crown segmentation was demonstrated.

What do influence the results?

There is a lot of interaction between the data and all the parameters of a segmentation algorithm, mainly the spatial and spectral resolution, or the differences in crown sizes.

Spatial resolution influences the size of a crown in the image. With the size of the crown under 4-5 pixels it is impossible to identify the crowns correctly. This is the first (lower) boundary of spatial resolution. But with the spatial resolution being too high, inadequate details occur and local maxima approach fails with several maxima found within single crown. So there is the second (upper) spatial resolution boundary. Pixel size of 80 cm used in our study is serving well — however pixel size of 20 cm used for the validation is too high for the presented algorithm.

Spectral resolution is less important for the segmentation because we averaged the bands into grayscale image. However it is a valuable opportunity to have spectral bands that include vegetation spectral information. Spectral agreement was not taken into consideration in the described analyses, more studies are needed.

Primary individual tree detection algorithms were proposed for relatively homogenous stands of coniferous species. We deal with heterogeneousness using masks and adaptive approach. The applicability of the results is obviously not universal and specific site characteristics must be taken into consideration.

Differences in tree crown sizes according to tree age composition are caught up well with adaptive approach. Both histogram equalization and local maxima detection are performed using a variable window size. It provides suitable results for different tree crown sizes and shapes. On the other hand the computational time increases significantly when different parameters are needed for each pixel.

After the above-mentioned input conditions, let's discuss the internal conditions of the segmentation process. Computation of the average brightness image over selected spectral bands, as well as using the classification mask has the aim to suppress or even to mask out the non-tree areas. These are still uncertainties present in the input conditions; especially the quality of the classification mask, which is however not a question of this paper. On the other hand better classification mask implies better tree crown detection results.

Adaptive approach used in the following steps of tree crown detection depends on appropriate choices of variable window size. Recommendations for equalization, filtering and local maxima detection are mentioned in the Methods chapter. Expected tree crown size and spatial resolution play the major role.

In the seeded region growing process a distance from a seed is a last stopping condition. It stops the growing in cases when the other conditions fail to work correctly. We can't expect entirely circular tree crowns, so a distance from a seed should be set slightly higher than the expected tree crown radius.

Brightness agreement is a fundamental condition to be fulfilled to identify tree crowns. After histogram equalization we have a uniform brightness distribution over both exposed and shaded crown parts. Lower limit for brightness agreement covers wider range of brightness over the region of interest and has the strong effect on the other stopping conditions. But the brightness distribution should be uniform after the equalization; the tree tops should have the highest brightness possible everywhere over the image and that's why higher brightness agreement limit is recommended. Values of 40 and 50 percent worked well in our example.

Spectral agreement was not required in our example. It can help when a significant difference in brightness is missing on the edge of the crown. That's why selected spectral bands are recommended to evaluate a spectral agreement.

Voronoi diagram is used as a preliminary conception of forest area division. It is necessary to distinguish two trees standing next to each other. Corrections made on the original Voronoi diagram are recommended to comprehend different tree sizes and shapes.

Final post-processing depends on expected output needed for subsequent usage of the results.

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