ALGORITHMS FOR THE AUTOMATIC DETECTION OF TREES IN LASER SCANNER DATA

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ABSTRACT:

Laser scanner data can be used to describe the state of forests and its changes as a base for forest management activities. An automatic evaluation of typical forest parameters using laser scanner data enables the detection of trees with minimal user interaction. This paper describes an algorithm for detecting trees in a semi-automatic way. The detection runs in several steps beginning with filtering the scanned data to eliminate outliers in the point cloud. In the second step a digital terrain model (DTM) is generated. Based on the DTM, horizontal layers with a constant distance above the terrain are generated. Besides the interesting tree stems, these layers contain other objects such as bushes or tree crowns. To filter such objects in the layers, several methods are used. The residual tree stems in the layers are mapped as circle rings, which are detected by using a Hough-transformation and measured accurately by using a fit circle algorithm and a fit ellipse algorithm. For these standard pattern algorithms the layers are mapped on a regular raster and are saved in an image format with multi channels according to the different layers. The resulting set of circle parameters and the set of ellipse parameters contain the dimension and the position of the tree rings in a mixed-up form which is not sorted by individual trees. To rank them, the intersection of the tree ring area is used. In a final step a validation check of the resulting trees is done with a linear regression.

For the use of this method in a standard application the processing time is essential. The listed time span for the process sequence show that the filter methods for the raw point cloud and the extraction of layers out of the filtered point clouds are too slow. To improve running time for these methods another data concept for holding the raw point cloud is essential and has to be developed. Furthermore, the data volume for raw data and results is stated.

1. INTRODUCTION

In forest inventories parameters are recorded to describe the state of forests for management. Laser scanning can provide a new method to ascertain the common inventory parameters and to expand the inventory for new parameters.

The detection of trees in the scanned data is essential to estimate forest parameters. To use laser scanners in a standard forest inventory application, the tree detection has to run quickly and almost automatically.

A raw scanned data set contains a huge number of points. Each scan point belongs to a reflected object such as terrain, a tree stem or a tree crown. To detect tree stems, a step-wise separation has been developed and will be described in this paper.

For this investigation we used the panorama scanner IMAGER 5003 by Zoller+Fröhlich. This system offers a high accuracy within the millimetre-range. Our sample plots were scanned as a full panorama with a resolution of 10,000 x 5,000 pixels and a maximum range of 53.5 m. The scan data contains, aside from the 3D information of the scanned points, information of the intensity of the reflected laser beam. The data volume for each scan is 250 MB. A scan retains the range and intensity parameters with 16 bits/pixel and 15 bits/pixel respectively (Zoller + Fröhlich, 2004, Mettenleiter, 2003).

The sensor of this scanner utilizes phase difference measurements to capture the distance information. Because of the ambiguity problem, the system will always recognize a scanned point inside the first interval. Reflected points in the second or third interval are calculated to the first interval. This severely affects the quality of a forest raw point cloud because there is a high number of points calculated to incorrect positions.

Our sample plots were scanned from different view points. This guarantees an overlapping zone. Trees inside the overlapping zone are surrounded by scan points from various sides.

There is a distance of 10m to 15m between the scanner positions. To make sure that the different scans are using the same coordinate system the scan registration is done by artificial targets and tacheometer survey (Simonse, 2003, Thies, 2003).

2. METHODS

2.1 Pre-Processing of Raw Data

Because of the ambiguity problem of the range measurement a large number of incorrect points are included in the raw data. The incorrect points are reflected points outside the ambiguity interval which were calculated in the first interval. Such points usually have a lower intensity due to the longer distance to the actual reflected point. A defined intensity threshold of 500 is used as an initial filter.

At the edges of objects, the measured points are noisy. One reason for this is the diameter of the laser beam. A part of the laser beam is reflected at the edge and another part of the laser beam is reflected at another object behind it. The calculated distance lies somewhere between these two readings. (Staiger, 2003). To filter such points all 8 neighbouring scanned points are analysed. The angles between the direction from the test point to the scanner centre and the direction between the test

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point to its neighbouring points are inspected. If one angle is greater than 170° the test point is filtered out.
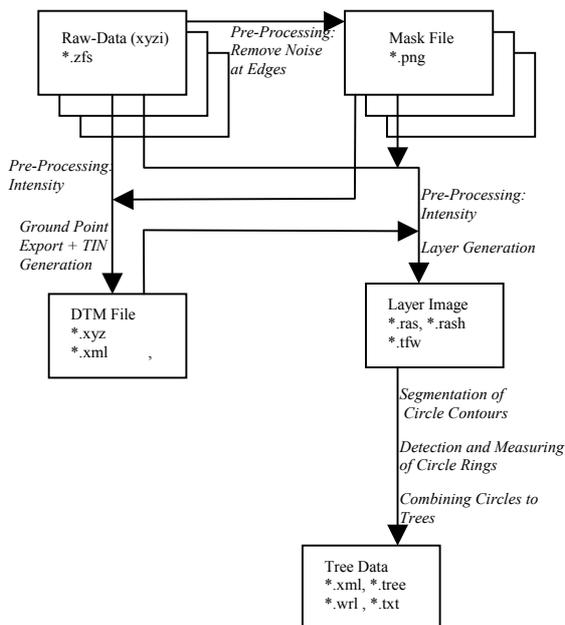

Figure 1. Process Flow

2.2 Creating the Digital Terrain Model

The digital terrain model (DTM) is generated by using a regular horizontal grid with a regular cell size of 50 x 50 cm. The grid is stretched over the sample plot. For each grid cell the scan point with the lowest Z-value is selected and pre-specified as a ground point. However, not all grid cells containing scan points are pre-specified well. To eliminate them, several filters are used.

An initial filter is the maximum value for the z-coordinate. All points above the maximum cannot be a part of the ground points and will be removed from the list. The predefined value for the z-maximum is 10m above the z-value of the scanner position and can be changed by the user.

Another filter uses an exclusion cone around the scanner centre with a predefined dihedral angle of 45°, which can also be changed by the user. All scan points inside the cone are eliminated from the dataset.

Finally a visual test is essential and an interactive correction will be done manually. Points that are obviously not part of the surface will be removed from the dataset by using an eraser function in 3D.

The dataset of ground points is finally matched to a triangular irregular net (TIN) by using a Delaunay triangulation (Simonse, 2003, Aschoff, 2004).

2.3 Tree Recognition

To find tree stems and to investigate their dimensions the diameter at different heights is determined and then used for the approximation of the tree stem. For this, step-wise processing is used. The steps are as follow: generation of layers, segmentation of circle contours, detection and measuring of the circle rings, combining the circles to tree stems.

2.3.1 Layer Generation: Horizontal layers are cut out of the scanned point clouds. The tree stems are displayed in the layers as contours of circle rings. Depending on whether the tree stems are covered completely or partially by the laser scanner data, the circle ring contours are either completely closed or partially unclosed. If only one laser scan is used the contours are displayed in general parts of circle rings. To find the circle rings in the layers and to measure their diameter standard pattern recognition methods are used.

The diameter of a tree stem has to be related to the height above ground. For this reason the horizontal layers are cut out equidistant to the terrain surface. Each scan point of the pre-filtered point cloud is tested for its vertical distance to the terrain and is put to the layer of corresponding height level. The relating terrain level is taken from the DTM model generated by the same raw data and the above described method for creating a DTM. This results in data sets for each layer of 3D points.

All layers are 10 cm wide and lay between 0.5 and 20 m above terrain. The vertical distances between layers are 0.5 m. Additional layers at 1.2 m, 1.3 m and 1.4 m are cut out for precise modelling of the diameter at breast height (DBH) at 1.3 m height. At the height of 0.6 m, 0.7 m, 6.9 m and 7.1 m additional layers are cut out, as well.

In order to use standard pattern recognition methods, each layer is converted to a regular raster image with a pixel size of 1 x 1 cm. For this conversion, each 3D point of the layer is transformed to a raster pixel by using the horizontal point position. The total number of scan points per pixel is inserted as a grey value in the raster image. At a circle contour the grey value is relatively high compared to the rest of the image. All layer images of a plot are saved in one binary file with the file extension *.ras. In a appropriate *.rash header file the corresponding information of image size, number of images and layer heights are saved. For georeferencing, a world file is used, which records scale information and pixel position in world coordinates. The format for the *.tfw world file is the same as the world file format of ArcInfo by ESRI (ESRI, 2004).

The layer images contain not only contours of tree circle rings, but also contours of branches, leaves and shrubs. To minimize errors at the circle adjustment a segmentation of the circle ring contours using the layer image is done. The results are placed in a region of circle ring contours.

2.3.2 Segmentation of tree circle contours: A larger density of scan points exist on tree stems. This amounts to a larger density of scan points at layer circle ring contours and consequently a larger grey value in the layer image at circle ring contours. To segment the layer image to a binary region a minimum grey value threshold of 5 is used. This binary region contains all objects with a higher grey value of 5 (which are circle ring contours , bushes, branches and leaves). Layers resulting from only one scan contain less grey values in the layer image. For this reason the minimum grey value threshold is modified in this case to value 2.

To eliminate contours which do not belong to tree circle rings the following methods are used: In a first step noise is removed. For this, each contour pixel is investigated for all four neighbours. All pixels without any connected neighbours are removed. After this a closing operation with a closing circle radius of 2.5 is used to close small gaps between adjacent regions and holes.

The resulted contour regions have to pass another 4 tests. First the area of each contour segment is calculated. If an area is smaller than the defined minimum of 9 pixels, the segment is removed. After that the largest inner circle of each contour segment is calculated. If an inner circle is larger than the
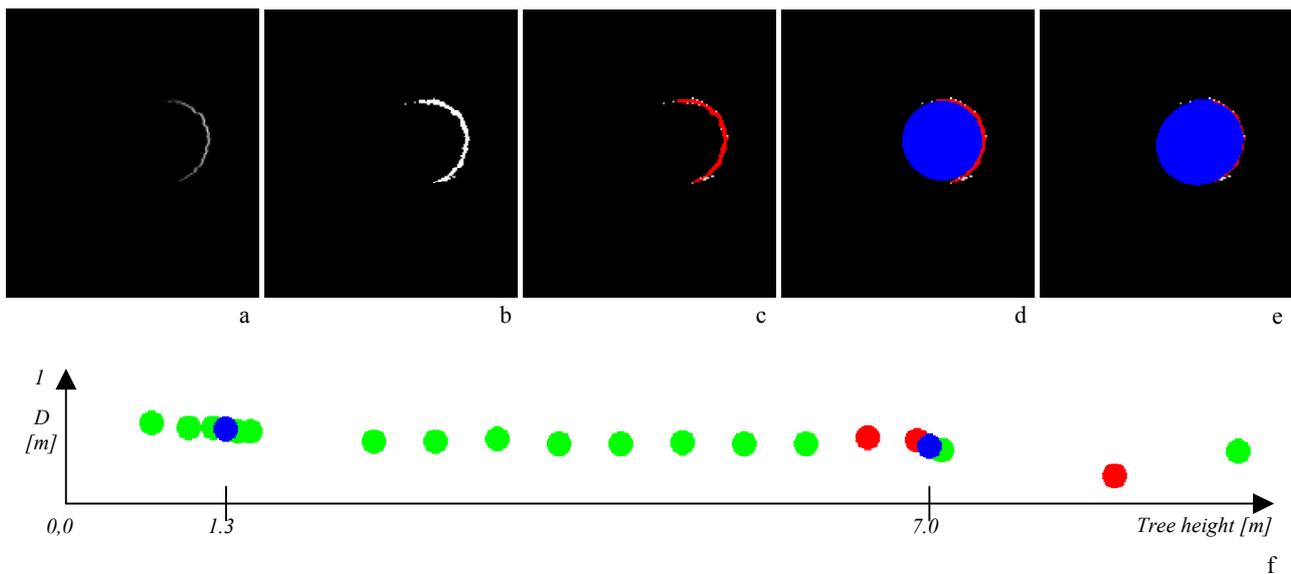
Figure 2. Segmentation and Detection of circle rings. Combination to trees. a) Layer image with a circle ring created by one scan. The grey values are equal to the number of scanned points per pixel. b) Region of all image pixels with a minimum grey value of 1. c) Segmented tree circle contour is shown in red. d) Best fit circle in the contour of circle ring. e) Best fit ellipse in the contour of circle ring. f) Diameter-height diagram of circles of one tree. Green and red dots are diameters detected by Hough-transformation and extracted accurately by fit circle algorithm. The red dots are filtered out using a linear regression and not used for further processing. Blue dots are estimated diameters for DBH and diameter at a height of 7 m.

maximum value of 7 pixels, the segment is removed. Third, the smallest surrounding circle of each contour segment is calculated. If a surrounding circle is lower than the minimum value of 4 the segment is removed. Lastly a shape factor for the circularity of each segment is calculated. Because the contours of circle rings are only surrounding contours, the area of contours are not circular. If the circularity is larger than the minimum of 40 %, the contour segment is removed.

2.3.3   Detection and Measuring of Circle Rings: Using a Hough-transformation circle rings in the contour regions are detected. A Hough-transformation identifies circle rings of a predefined diameter. (Pitas, 2000) Because the diameter is not known before the circle rings are detected, the Hough-transformation runs with different diameters. It starts with a diameter of 100 cm. In several processing steps the diameter is reduced by increments of 10 cm until the minimal diameter of 20 cm is reached. The result of the Hough-transformation is the position and the diameter of circle rings of low quality.

To increase the precision of detected circle rings, an approximation of the circle ring contours by circles is used. To separate the contour points of a circle ring, the detected Hough-circle is expanded by 10 % to ensure the identification of all pixels belonging to it. The intersection area of the expanded Hough-circle and the region of circle ring contours contain the contour points of one circle. Due to these points a circle will fit best. The resulting circle has a higher accuracy for position and diameter. The fit circle is calculated by using an algebraic algorithm, which minimizes the algebraic distance between the contour points and the resulting circle (Halcon, 2004; Simonse 2003).

An advanced model for approximating the contours, is to fit the points too an ellipse. The results of the fitted ellipses are assigned to the corresponding fitted circles and saved with them to the output.

As a validity check the diameter of the Hough-transformation and the diameter of the fitted circle is compared. The maximum tolerated difference between them is 50 %. If this value is exceeded this circle is removed from the circle list and no longer used.

2.3.4   Combining Circles to Trees: Detected circles of layer images have no information about the tree to which they belong. To fuse the circles to trees, all circles of each layer are drawn in one region. Circles of the same tree overlay each other and produce segments. The segments of the different trees are naturally not connected. In a first assumption each segment is classified as a tree. To validate them, the number of circles which form a segment is counted. If there is a segment with fewer than 5 circles of different heights, this segment is removed from the list of trees.

The list of trees still contains outliers of wrongly classified segments. In accurately classified segments incorrect diameters are also possible. To eliminate such outliers a robust linear regression is used. Through the diameter-height values of a tree a line will fit. All circles with a deviation from the line higher than the standard deviation are removed from the list of circles. As a validity check the gradient of the fitted line is compared with the minimum taper of 0 cm/m and the maximum taper of 5 cm/m. Trees falling below the minimum taper or exceeding the maximum taper are removed from the tree list.

To estimate diameters at breast height the closest 4 diameters to 1.3 m height are selected. Two of the diameters must be below 1.3 m and two diameters have to be above 1.3 m height. If there is a diameter directly at 1.3 m height, the selected number of diameters is increased to 5.

The value of the diameter at 1.3 m is estimated by using a linear regression. For this a diameter-height diagram of the selected circles is drawn. Through the 4 or 5 drawn dots a line is fitted and used to calculate the diameter value at 1.3 m height.

In some cases the number of diameters below or above 1.3 m is less than the required. In this case the distribution of selected diameters is changed to a ratio of 1:3 or 0:4. The distribution of 1:3 is preferred because the diameter at 1.3 m is interpolated by either one diameter below or above 1.3 m height and three diameters on the opposite site. In the case of a distribution of 0:4 the DBH become extrapolated.

The diameter in 7 m height is estimated by the same method as the DBH.

A the tree base point the position of the lowest found circle and the z value of the DTM at this position are used.

3. PROCESSING TIME

The time needed for data collection and for the data analysis is definitely an important criterion for acceptance in forest inventories.

To observe a forest scene with 5 scans takes approximately 3 hours. The largest amount of time is needed to put targets on trees for registration, to assure of free views to targets from each scan, to survey the targets and to carry the scanner hardware to the different views. In difficult terrain the time required can increase. The pure data collection with the scanner only takes 2.5 minute for a full panorama view with 10,000 x 5,000 pixels.

To observe a forest scene with one scan takes approximately 15 minutes. In this case the registration is not needed, which shortens the time a great deal.

Process	Forest scene with 5 scans [h:min]	Forest scene with 1 Scan [h:min]
Observing in forest	3:00	0:15
Remove noise points at edges by using angle criterion	3:20	0:40
DTM creation	0:15	0:10
Layer export	10:00	2:00
Tree recognition	0:10	0:10

Table 1. Processing time for data collection and data analyses.

During the data analysis the layer exports requires the largest amount of time. Each scan is read column by column and each scan point is tested for belonging to a layer. Exporting a forest scene with 5 scans takes approximately 10 hours on a Intel Pentium 4 CPU 2.0 GHz. During the pre-processing of raw data, removing noise points at edges by using angle criterion also takes a great deal of time. For one scan approximately 40 minutes are taken. Neither of these processes require interactive activities and therefore can be run in batch processing mode.

4. DATA VOLUME

One raw data scan with a resolution of 10,000 x 5,000 scan points has a data volume of 250 MB.

Both pre-processing methods reduce the data volume. The degree of reduction depends on different factors such as composition and density of trees. If the filters are used directly on the raw data, the number of scanned points is reduced to approximately 50 % for each filter. If both filters are combined the reduced number of pixels is approximately 75 %.

The results of pre-processing are not saved as data files with 3D points. For filtering by the minimum intensity only a parameter

file is saved. The decision to filter out a point is done as a condition during processing of the laser data. For filtering the noise points at edges a filter mask is saved. The filter mask is an image with the same pixel size as the raw scan image containing only black and white pixels. White pixels are hidden scan points in the scan image. The filter masks are saved as a PNG image file. A filter image of 10,000 x 5,000 pixels has an approximately data volume of 10 MB.

The created digital terrain model is saved as a 3D VRML model or as an XML data file. As an interim result an ASCII ground point file is also saved. For a forest scene the volume of all 3 files is approximately 1.5 MB.

Object	Data volume on hard disk [MB]
ZFS raw data scan	250
Mask file, PNG format	10
Ground points for creating the DTM	0.2
DTM TIN, XML format	1.0
DTM TIN, VRML format	0.4
Layer image with 48 layers with 3,000 x 3,000 pixels per layer	410, 4.3 (zip)
Circles of trees in XML or TXT format	<0.1
Circles of trees in VRML 3D-Format	0.5

Table 2. Data volume for saved files of data processing.

A layer image for detection of circle rings with 48 layers and a size of 3,000 x 3,000 pixels per layer has a data volume of 410 MB. Using ZIP compression the data volume can be reduced by a factor of 100.

The results of tree recognition have a total volume of below 1 MB.

5. CONCLUSION

The methods described provide an automatic method of detecting trees in terrestrial laser scans of forest sites. To describe the trees the diameter at 1.3 m and at 7 m height are estimated.

The data collection and processing time is too high and must be shortened. Especially the observation of scenes using multiple views requires a lot of time. The acquisition effort for registration of scans has to be reduced. Ideally the registration will be done without any targets or other artificial objects.

During data processing the largest amount of time is required for working on the raw data. The pre-filtering and the layer export has to be shortened as well . Therefore another concept for data saving and processing is needed.

The data volume is acceptable except for the uncompressed layer image. A compressed image format should be used which can save multiple layers in a file without any data loss.

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