DESCRIBING FOREST STANDS
USING TERRESTRIAL LASER-SCANNING

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ABSTRACT:

A method for extracting forest parameters is described in this paper. The 3D point clouds derived from phase difference laser scanners in forests were processed in a step-wise separation. The first step contains basic filter methods to reduce raw data which, separates isolated points or deletes those artefacts resulting from the ambiguity problem. The next step includes using algorithms to isolate the main object categories of forest stands: terrain and trees. A digital terrain model (DTM) is calculated as a triangulated irregular network (TIN). Based on this, the point clouds are sliced at different heights above ground and included co-ordinates are projected in 2D layers. The following steps use image analysis methods to derive the single tree positions and diameters in the different layers. A Hough-transformation is used for the detection of the trees and a circle approximation is used to localise the tree exactly. For a precise model of a tree stem, a triangulation is conducted using the power crust algorithm.
The developed methods enable one to measure some of the standard forest inventory parameters. Unfortunately, important parameters such as tree species and tree height have not yet been extracted from the scanning data. Indeed, for the acceptance as a standard method, these parameters play a key role. Further work has to investigate an automatic way to extract these parameters from the point cloud.

1. INTRODUCTION

In Germany forest inventories are repeated periodically every 10 years. In a grid of 100x200m, sample plots with a radius of 12.5m are assessed. Principle information measured for the standard inventory include tree species, diameter at breast height (DBH, breast height=1.3m), branch-free bole length and tree height. Current recordings of the inventory parameters are measured manually.

In modern forest management an increasing in quality of already analysed parameters is not only needed, for scientific questions and ecological aspects, new parameters have to be investigated.

Laser scanning offers new possibilities in forest applications. The fast collection of data with a high resolution and accuracy can provide standard forest inventory information as well as parameters describing quality aspects of trees such as taper, sweep, number of branches, etc.

A raw scanned data set contains a high number of points. Each scan point belongs to a reflected object such as terrain, tree stem or tree crown. To investigate parameters of these objects, a classification of the scan points is essential. Furthermore, there are a high number of incorrect points in the raw data set. For this reason, the step wise separation starts with a pre-filtering of the raw point cloud. In the resulting data set several methods are used to generate the sought out parameters (see Figure 1).

2. METHODS

2.1 Data Collection

For this investigation we used the panorama scanner IMAGER 5003 by Z+F. This system offers a high accuracy within the millimetre-range for a full panorama scan with a maximum resolution of 20,000 pixels vertical and 36,000 pixels horizontal. To retain our data volume well, our sample plots were scanned as a full panorama with a resolution of 5,000 x 10,000 pixels. 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 Bit and 15 Bit respectively (Zoller + Fröhlich, 2004).

The sensor of this scanner utilizes phase difference measurements to capture the distance information. The IMAGER 5003 is supported for two different ranges: 25.2m and 53.5m. 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 will calculate to the first interval. This hardly affects the quality of a forest raw point cloud. In a crown of a tree, as well as in brush wood, the distance of views are extremely variable. On leaves and branches the reflecting area is small. Between them long views that are farther away than the ambiguity interval is frequently reached. The resulting point cloud detects in these sections incorrectly calculated points.

Our sample plots were scanned from different view points. The scanner positions have a distance of 10m and 15m between each other. This guarantees an overlapping zone of the different scans. To register the point clouds artificial targets are used.
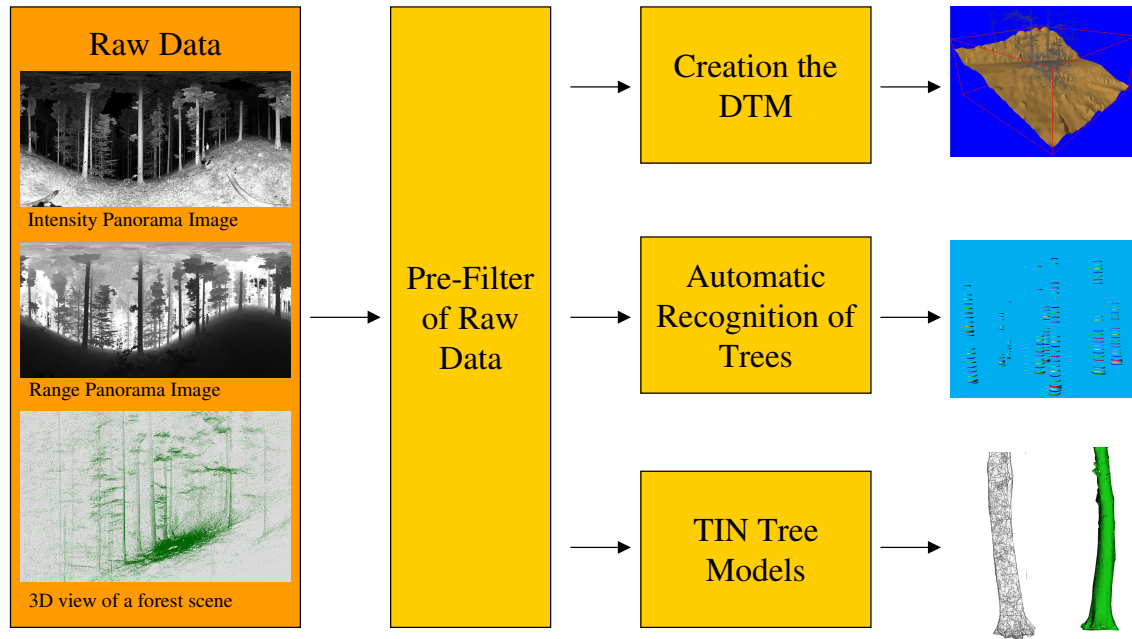
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Figure 1. Data flow for laser scanning in forest applications. Left. The raw data produced by the laser scanner viewed as a range and intensity image and in a 3D view. Middle. Stepwise separation of the point cloud by using different filters. Right. Extracted Parameters and Models.

These targets are also used for geo-referencing the scan plots into the German national co-ordinate system. The targets are measured with a total station. Each scanned point cloud is transformed in this tacheometric system by using a 6 parameter transformation. As targets, we use plain A4 size printed paper. The maximum distance of a scanner to a target to insure a good localisation of the target centre is limited to approximately 20m. Therefore the area outside this distance is extrapolated. The residual registration errors are strongest in the extrapolated areas. In particular we find this problem in the upper part of tree stems and crowns. To minimize this problem we try to install targets on a higher level above the ground. Because of the dangerous access, view distances in the vertical direction are often not within the maximum range of view distances to targets.

2.2 Pre-Filtering of Raw Data

Because of the ambiguity problem the raw point cloud contains a large number of incorrect points. Fortunatly, those detected points which are farther away have a lower intensity than those which are closer. For this reason most reflected points out of the ambiguity interval have a low intensity. This difference in intensity is used as an initial filter by defining a minimum threshold for the intensity value.

Another reason for incorrect points is the divergence of the laser beam. Even with the small diameter of 3mm at 1m distance and a beam divergence of 0.22mrad, the laser beam will be reflected at different distances at edges. A part of the beam will reflect in the foreground and the other in the background. The calculated scan point is somewhere in between (Staiger, 2003). To eliminate these incorrect points the scan direction and the direction between neighbouring points are used. Each scan point will be tested for the angle between the direction to the scanner and the eight neighbouring pixels. Scan points with an angle greater than 170° to one neighbour minimum are filtered out.

Another filter is used to eliminate isolated points. A point is considered isolated if there is no neighbour pixel in the range image within a distance of one meter.

2.3 Creating the Digital Terrain Model

To generate a digital terrain model (DTM) from unclassified point clouds we separated a sub data set out of the whole point cloud. The sub data set should include only points of the terrain surface. To obtain these ground points, a horizontal grid with a regular cell size of 50 x 50 cm is stretched over the sample plot. In each grid cell the coordinate with the lowest Z-value is selected and pre-specified as a ground point. However, not all grid cells contain a scan point on the terrain surface. Due to the lower coverage of shrubs and shadow behind trees, there are quite a number of cells without any scan points, or else with scan points that are not part of the terrain level (see Figure 2 above), This problem depends not only on the forest density. On the downhill side of a steep plot there are much fewer scan points than on an uphill side. Furthermore, in a steep stand with intense variation, the terrain will become obstructed. To filter points that are not on the terrain, several filters are used.

As an initial filter a maximum value for the z-coordinate is determined. Points above this limit 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. In extreme steep stands this predefined value has to increase. In flat stands this value can decrease to improve the result extreme. Altogether, this filter performs much better on flat stands than on steep slopes.

Another filter tests against an exclusion cone around the scanner centre with a a-priori dihedral angle. Scan points inside the cone are also eliminated from the ground point dataset. This filter performs well close to the scanner in steep terrain. When used uphill this filter improves the result. Downhill, however, this filter improves less the quality of the result.

Both methods remove a large number of errors. However, a visual test is still essential and 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 a 3D view (see Figure 2 below). Finally, the ground points are matched to a triangular irregular net (TIN) by a Delaunay triangulation.

The small grid size of 50x50 cm for the selected ground points is too great in resolution in a homogeneous surface. For this reason the resulted TIN has more triangles than are necessary. An automatic reduction of the TIN based on the angle deviation of neighboured areas therefor follows. A predefined deviation of the angle decides which trinangles will be merged.
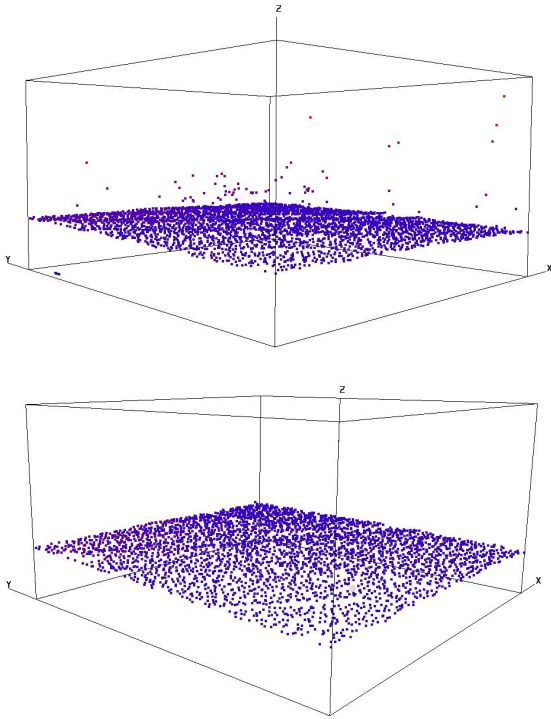

Figure 2. For extracting a Digital Terrain Model (DTM) a regular raster is used to separate a few ground points out of the full scan point cloud. The figure above shows the pre-filtered ground points by using a regular raster of 30x30m with a grid size of 50x50cm. Below the resulting filtered ground points are a result of interactive correction.

2.4 Automatic Recognition of Trees

Important objects in forests are trees with their position and dimension. For a standard data analysis, an automatic process for localising trees is essential. In order to achieve this aim a method has been developed which identifies trees by using a Hough-transformation (Halcon 2004 ;Pitas, 2000; Simonse, 2003).

In a horizontal layer, cut from the scanned point cloud, a tree stem is mapped as a circle or a circular arc. Because of the changing terrain the layers have to be within an isochronous distance to the terrain in order to cut layers from the trees in the predefined terrain level. For this the above described DTM is used.

Even with the filter methods to eliminate incorrect points in the raw data, the result of a single layer is also influenced by errors
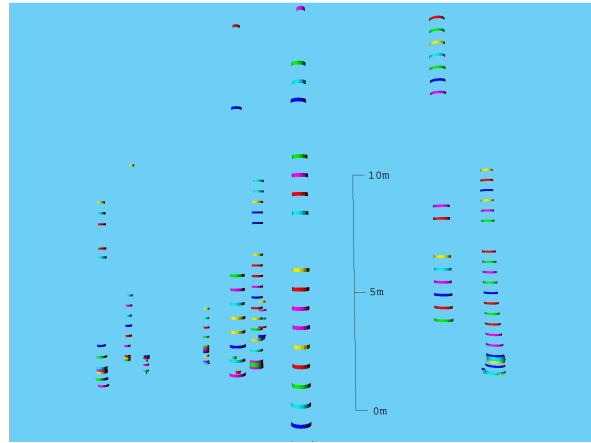

Figure 3. Found Tree Circles in layers of 10 cm thickness in a perspective view.

and artefacts. To obtain reliable information of the trees, layers at different levels are cut. The results of the layers in the different levels will then be merged to improve the results. Furthermore, the taper is also relevant and can also be investigated by using different layers.

The layers are usually 10 cm thick and localised between 1 and 20 m above the ground. The increment of the layers is 0.5 m. Of special interest to forest management is the diameter at 1.3m above ground. To properly obtain this value, additional layers at 1.2m and 1.4m are extracted. The diameter at 1.3m will be verified by the additional diameters at 1.2m and 1.4m.

To use standard pattern recognition methods, the layers are mapped to a regular raster with a cell size of 1x1 cm. For detecting circles in this raster image, a Hough-transformation, which requires a predefined diameter, is used. Because the diameter is not known before the algorithm is started, we begin with a diameter value of 100 cm and reduce the diameter in increments of 10 cm. The results of this are positions and diameters of a low precision. To improve the position and diameter a fit circle algorithm is used. The determined Hough circle is expanded by 10% to ensure the identification of all pixels that could be part of the stem. On the selected pixels an algebraic algorithm is used to fit the circle precisely. This algorithm minimizes the algebraic distance between the contour points and the resulting circle (Halcon, 2004; Simonse 2003).

Unfortunately not all detected circles represent a tree stem. Some circles are the result of noisy points or scan points in shrubs or tree crowns. To eliminate such circles a stepwise method is used. The first step investigates the position and dimension of the lower 7m portion of the trees. All detected circles in this section are put on top of each other with common intersection areas. The circles which belong to the same intersection belong together and are circles of the same tree. To reduce errors, a minimum of 5 circles in one intersection is necessary to define a tree.

The second step investigates the upper part of the trees above 7 m. In this section branches hardly influenced the recognition. For this reason, in the upper part only circles are used to try to find the position of the already detected trees. For this the same Hough transformation and fit circle algorithm as in the first step is used. The investigated area, however, is different. Only in the closer neighbours of the already found trees will the layers be investigated for additional circles.

As a validity check a linear regression is used. To ensure that a circle dataset of a tree has no strongly decreasing diameter in

Figure 4. Tree point triangulation by power crust algorithms. Left is the points cloud of a oak tree with 800,000 points. In the middle the reduced point cloud with 50,000 scan points. Right the generated triangulation.

the middle of a stem, a fitted straight line through the diameter values is used. This is also used for a tapering check. All detected trees have to show decreasing diameter with increasing height.

2.5 TIN Tree Models

A precise model of a tree stem is achieved by a triangulation of its surface. For triangulation the points of an object have to be separated from the full point cloud. Ideally, only points on the surface of the object are used for the triangulation. In order to separate trees in the point cloud several methods are combined. The raw point cloud is filtered to eliminate false points due to the ambiguity problem and the divergence of the laser beam. The methods are described above. In the resulting range image most errors are removed. To separate the single tree stem, a region growing method is used. Finally, an interactive monitoring processes the data by using selection tools and an eraser in the intensity or range image.

At least two views are needed to generate an all-around model of a tree. To minimize the errors on the tangential area of the point clouds, in general three or four views of a tree are used. The point cloud of one tree with four views easily reaches up to 800,000 points (see Figure 4 left). This high number of scan points is reduced for a good triangulation. Usually approximately 50,000 points are used for a tree stem of 8 m length (see Figure 4 middle).

To triangulate the scan points the power crust algorithm is used (Amenta, 2001) (see Figure 4 right). The achieved triangulation offers a high accuracy of volume calculations for a tree stem. Volume is an important parameter for the price of a stem as well as for the investigation of tree growth. With a repeated scanning in a time series, growth can be calculated and ecological evaluations become possible.

The resulting triangulation can be provided in the 3D visualisation format VRML and in a XML data format. This offers an easy visualization and transfer to application in other processes.

2.6 Reconstruction of Tree Crowns

For ecological as well as economic aspects the tree crown provides information about the actual state of a tree. Interactive measuring in the point cloud is possible and enables the investigation of the tree crown. For a standard application an automatic reconstruction of the tree crown is needed. A method for automatic reconstruction has already been developed (Pfeifer, 2004; Gorte, 2004).

3. CONCLUSION AND FURTHER PLANS

The shown methods for describing forest stands enable a part of forest inventory parameters to be measured remotly. In order to be used in a standard application, the detection of the tree species is essential. So far the tree species is not automatically recognized and is defined by the operator manually. Furthermore, the tree height is an essential forest parameter as well. Because the tops of the trees can not be automatically detected, an extrapolation of the tree height by using the diameters at different heights is necessary. Unfortunately, a correct calculation of the tree height has not yet been reached. It seems that the reasons include the limited height of free views to stems and the accuracy of the calculated tree diameters. For a good extrapolation, the highest diameter of the tree stem which has an accurate value is most importand. These height levels are mostly hidden by branches so it is difficult to obtain an accurate value.

In order to use laser scanning in standard forest inventories, the tree species and the tree height have to extracted. For this reason, in the future, the methodology for tree recognition has to be verified. The calculation of the tree stem diameter in the higher part of the stem also has to improve. To recognize tree species an automatic mode of detection has to develop.

A second aspect for acceptance of these methods in forest inventories is the economic aspect. For this reason a high level of automatism is essential. The developed methods indicate semi automatic data processing. With a better detection of outliers in the raw data, as well in the detected parameters, the manual interaction can further be reduced. For this reason, further work will continue in the development and analysis of methods for the better detection and deletion of outliers.

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