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AUTOMATIC PLOT-WISE TREE LOCATION MAPPING USING SINGLE-SCAN TERRESTRIAL LASER SCANNING

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ABSTRACT

The application of terrestrial laser scanning (TLS) has received increasing attention in the quantitative forest inventories. Both single-scan and multi-scan TLS can be employed for the forest parameter retrieval. The multi-scan mode captures an ideal data set, which in general provides whole tree coverage and leads to accurate tree trunk detection and modelling. The single-scan data is, however, of high practical interest because of its high collection efficiency and low processing expense achieved by avoiding the multi-scan point cloud matching. In this paper, an automatic plot-wise tree location mapping algorithm by using single-scan TLS is presented. The method detects the tree trunk based on range data and tree trunk model. The test area was a single-layer, pine-dominated forest. The reference data were interactively measured on-screen on the TLS intensity image by an operator. Eighty-five percent of trees that were manually found on the intensity image inside 60m range could be automatically found. The complexity of the forest scene and the occlusion effects are the main limiting factors in the application of the method. The experimental result shows that the single-scan TLS is a feasible technique for plot-wise tree location mapping.

1. INTRODUCTION

The detailed forest inventory based on remote sensing has become more practical in the Nordic countries in the last decade, mainly driven by the applications of airborne laser scanning (ALS). Experience has shown that the retrieval of the most important parameters, e.g. stem volume, at stand level from ALS data performs as well as, or better than, photogrammetric methods, and better than other remote sensing methods. However, currently applied ALS processing methods, i.e. area-based forest inventory according to Næsset (2002), requires extensive ground reference data from sample plots for data or model calibration. These references are, presently, collected at plot-level by traditional field inventory, which include: the mean tree height, basal area, tree species, and stem volume.

In the near future, individual tree-based forest inventories will be more widely accepted. It will require that the reference data are available for model calibration in a certain number of sample plots, where individual tree features include basic geometric attributes, such as the individual tree stem and crown position, height, diameter at breast height (DBH) and crown projection area. Thus, more cost-effective, automatic processes are required in the forest inventory.

Terrestrial laser scanning (TLS) provides an efficient solution for tree-wise and plot-wise tree parameter retrieval in mainly one-storey forests (e.g., Watt and Donoghue, 2005; Henning and Radtke, 2006). The major advantages of applying TLS in forest field inventories are the high collection efficiency and the fully/partly automatic process. Both single- and multi-scan patterns can be employed in the TLS data acquisition of forest inventories.

In the single-scan mode, the scanner is placed in the middle of the plot and one full field-of-view (FOV) scan is performed. The typical FOV is 360° in the horizontal and around 300° in the vertical direction. This scanning pattern assumes that the geometric parameters, e.g. location and DBH, of most trees in the plot can be obtained in one scan. It is also possible to use several single-scans, inside the same plot, without registration of the scans at point cloud level to improve the trunk detection percentage. In that way, the reference targets are not needed and the data acquisition is simpler.

In the multi-scan mode, the scanner is placed in- and outside of the plot, and the plot is scanned by multiple scans with overlap. The scans are then registered to provide complete data set. In general, the multi-scan operation provides better trunk coverage and leads to higher accuracy. However, it is achieved at the cost of longer data collecting and processing time as compared to the single-scan pattern, where the amount of data is smaller and the registration of different scans is not required.

In the plot-wise forest inventories, the basic characters extracted from the point cloud are the number and positions of trees. The TLS methods for the tree mapping can be performed in two-dimensional (2D) or three-dimensional (3D) space.

In the 2D space, the tree location is identified in a layer sliced from the original 3D point cloud (e.g., Aschoff and Spiecker 2004; Strahler et al., 2008; Maas et al., 2008; Tansey et al., 2009), or in the range image built from the row/column information based on the scanning geometry (Haala et al., 2004; Forsman and Halme 2005). The advantage of this idea lies in its simplicity. The amount of computation is usually modest.

The 2D layer is, typically, horizontally sliced at the breast height and with certain thickness (e.g., 5 cm). Points representing trunks are identified by point clustering and/or circle finding in the layer. For example, in Maas et al. (2008), points in the 2D layer were clustered by a square structure; a circle was fitted into the cluster; the cluster was accepted as a tree if it fulfilled certain conditions. It is also proposed to build multi-horizontal layers to improve the identification accuracy (e.g., Aschoff et al., 2004). As the layer is supposed to be parallel to ground surface, a local terrain flatness assumption or a digital terrain model generation are required to build the layer.

In the range image technique, pixels in the planar range image are segmented according to the local properties. In Haala et al. (2004), the surface types of pixels in the range image were first employed in the region segmentation and then in the trunk identification. In Forsman and Halme (2005), the segmentation was based on range measurements and carried out in an approximately perpendicular direction to the expected object orientation. Trunks were then identified by the circle fitting. There has been much work on range image segmentation in the computer vision community. Due to the similarity of range image and 2D image, most of the image segmentation techniques, such as edge detection, region growing and pixel clustering, can be applied to range image segmentation (Hoover et al., 1996).

In the 3D space, the geometric properties of each point are studied in its neighbourhood. This idea does not assume the ground is flat and can be used when the image structure is not available. The disadvantage is, however, the amount of computation is larger than that in the 2D space. In Lalonde et al. (2006), a distribution model is estimated from the training data, and objects are classified by the point geometric features and the distribution model. In Liang et al. (2011), a local coordinate system is established for each point in its neighbourhood; a point is identified as a trunk point if it presents low variance along one direction in the local coordinate system and had a close-to-horizontal normal vector in the real world coordinate system; the tree trunk model, a series of 3D right circular cylinders, is built to locate the tree position.

The main purpose of this study is to develop an automatic plot-wise tree mapping algorithm based on the scan geometry and with minimized prior assumptions, and to validate the method in the pine forest environment.

2. MATERIAL AND METHODS

2.1 Study area and data acquisition

The study area is a pine-dominated (Pinus sylvestris L.), one-storey forest located near Kajaani in eastern Finland. The TLS data set, 3D points with row/column information, was collected in November 2007 using a Faro 880HE80 terrestrial laser scanner (Faro TLS hereafter), which is a high-speed scanner with a data acquisition rate of 120 000 points per second. The scanner uses continuous laser to measure the distances based on phase-shift measurement. The operating wavelength is 785 nm, and the FOV is 360° × 320°. The measurement resolution used in this study produced a point spacing of 0.6 mrad (6 mm at 10 metre distance) within the single-scan point cloud. The whole single-scan data set, organized as an image (planar view), is of the size 4305 rows and 9694 columns. The data employed in tree location mapping is a subset of the original scan, with the size 2500 rows by 2000 columns.

Faro Scene software (version 4) was used for the interactive measurements on the planar view on the computer screen to get the reference tree positions. The location of the tree trunk was visually determined by an operator and measured from the intensity image (planar view) of the scanned point cloud and verified by a 3D-view of the measured points.

The typical circular sample plot in the forest inventories is with a radius range from 8 to 15 metres. In this study, a tree location map, measured by the interactive interpretation from the intensity image, was used as the reference. It should be noted that the number of trees in the forest is larger than that obtained from a single-scan planar view image. However, trees in the distance, up to 70 meters away from the scanning position, were detected in the interactive interpretation. And this is good for verifying the tree trunk detection in the distance.

2.2 Faro scanner operating principle

The Faro TLS makes the measurement in horizontal and vertical directions, step by step, by a fast vertical mirror movement and a slower horizontal instrument movement. In the vertical direction, the laser beam starts from the scanner zenith at 90°, and the vertical angle (Theta) decreases to 0° at the horizontal line, then becoming a negative value. The smallest possible vertical angle is –70°. In the horizontal direction, the scanner turns 180° in a clockwise direction and scans the both sides of the scanner (forward and backwards) simultaneously. The view starts and ends at the same position in a full field of view scan, and the horizontal angle (Phi) ranges from 0° to 360°. The general operating principle is illustrated in Figure 1. The green disk shows one vertical scan line.

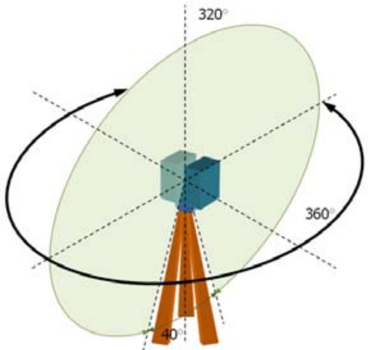

Figure 1. The general scanning principle of FARO 880HE80.

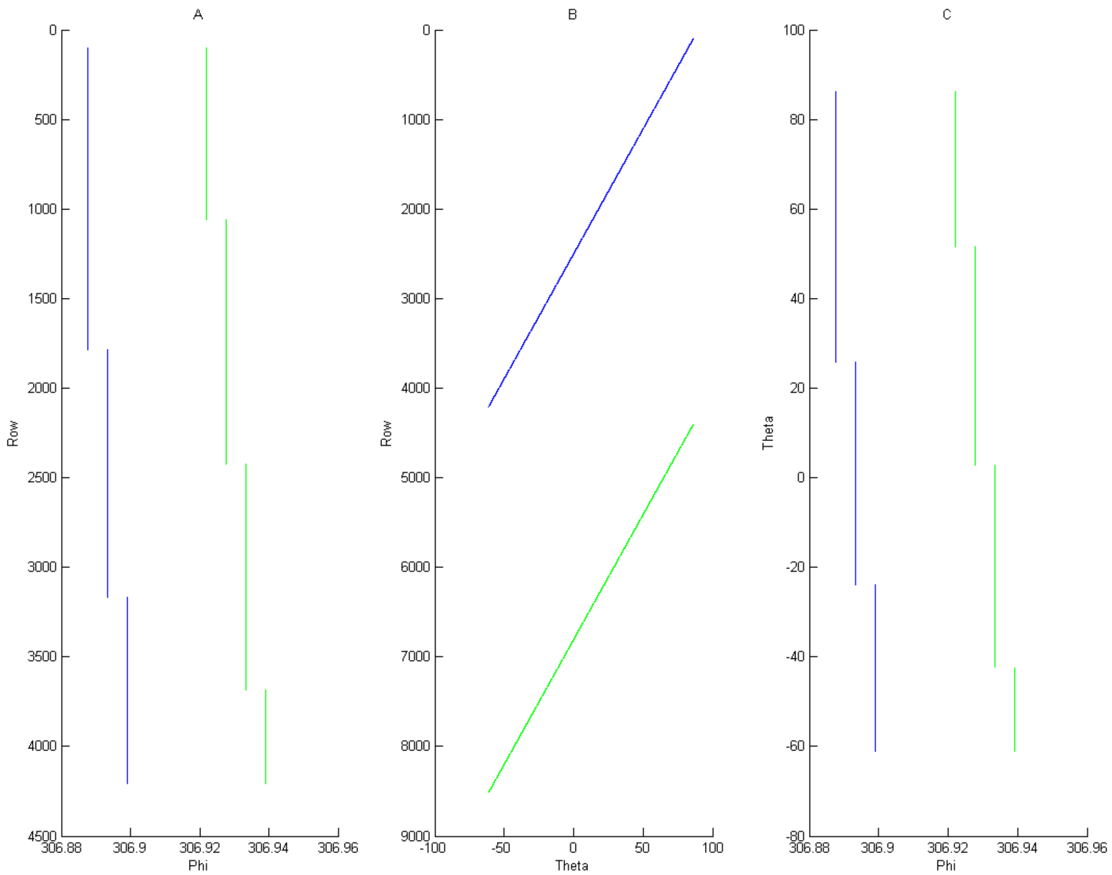

Figure 2. The detailed scanning principle. Two consecutive vertical scan lines are plotted in blue and green respectively. (A. the horizontal angle Phi and the row indexes; B. the vertical angle Theta and the row indexes; C. the angle Phi and Theta)

The detailed operating principle is illustrated in Figure 2, by the value of Theta and Phi of two consecutive vertical scan lines, i and $i+1$, in blue and green respectively. In Figure 2A and Figure 2B, angles are plotted against row indexes. In Figure 2C, the Theta is plotted against the Phi. An artificial row offset is employed in scan line $i+1$ in Figure 2B, as both scan lines are of similar value.

By assigned row and column indexes, 3D laser hits can be organized as a data matrix, where rows and columns correspond to scanner vertical and horizontal movements. In the data matrix, the vertical scan line i is assigned as column i; the subsequent scan line $i+1$ then goes to the right, with an increasing horizontal angle. In each column, the vertical angle decreases from the top to bottom, corresponding to the scanner zenith and foot. Different data matrixes, or images, such as intensity image and range image, can be produced when different information from laser hits is organized by row and column indexes.

Regarding the operating principle of the scanner and the organizing principle of data matrix, one basic, but important, fact is that two laser-illustrated points close to each other in the 3D object space would locate close to each other also in the 2D image space. It should be noted that the reverse principle is not true.

2.3 Tree trunk detection

The trunk detection is a process to identify the laser points belonging to an individual trunk from the original point cloud. The idea of detecting in the image space assumes that the image structure is available or can be reconstructed. It is, however, not always the case. The image structure may be destroyed or deleted at certain steps along the processing pipeline because of, e.g., the noise filtering or data volume reduction. It is also difficult to reconstruct the image structure for the point cloud merged from several scans around the sample plot. However, certain properties of the 2D image matrix make clustering in the image space beneficial. It is possible to simplify the computation by using the image structure.

The 3D spatial distribution of the points in the object space is implicitly expressed by the 2D spatial distribution of pixels in the range image. The point clustering in local 2D image space by spatial features functions similarly to that in local 3D space by XYZ coordinates. An exceptional is a case when a trunk is separated into two parts at the edges of the range image. It can be however compensated by certain searching strategies, e.g., taking boundary pixels of the image at both sides into consideration.

The scan line segmentation (Jiang and Bunke, 1994) performs well in the range image segmentation and is of interest in the laser scanning community. In Sithole and Vosselman (2005), the original ALS point cloud is structured into scan lines in several directions, and segmentation results are combined to get regions for the digital elevation model generation. In Forsman and Halme (2005), range measurements are segmented in an approximate perpendicular direction to the expected object orientation for trunk detection.

The scan line continuousness segmentation was developed for the trunk detection in this paper. The approach is based on the continuity property of the object surface, planar distance and segmentation in horizontal and vertical directions.

The surface of an individual object or an object group is continuous. TLS points, locating next to each other on an object, have similar positions in the 3D space. And, from one point, there is at least one path to any of other points on the same object, without travelling on the surface of others. This feature is roughly preserved for laser-illustrated 3D points in the single-scan TLS data organized as the 2D range image. There are, however, some exceptions. First, TLS works on sampling principle. The space between consecutive laser points varies according to the object feature, the scan geometry, and the distance from the scanner. For example, the distance of points next to each other on a trunk surface close to the scanner is much smaller than that on a discrete crown far away from the scanner. Therefore, 3D positions of laser points, next to each other in 2D range image, may be far away from each other. Secondly, foreground objects, e.g. branches and foliage, cast their shadow on background objects. In some cases, the path between two object points is occluded. The image space dimension is another possibility for this issue. The image border may cut the path. However, the continuity property is generally preserved, and the searching mechanism or post processing could compensate these exceptions.

To segment the data matrix, two one-dimensional (1D) segmentations, in horizontal and vertical directions, were first performed independently and then combined. In each 1D segmentation, the points were grouped if they were continuous in the sense of position and distance. A point in a group is within a certain distance and has the similar distance away from the scanner to at least one point in the same group. For example, in the vertical direction, a point is in a group if there is another point, in the same group, located less than 20 pixels away from it and the distance difference between them is less than 5 cm. Two 1D sets were then overlaid to form continuous regions in the way that initial groups were combined if there was an intersection between them. The minimum size of the region is set to be 300 pixels. Small regions were supposed not belong to a tree trunk.

In the continuousness segmentation, the range measurement acquired by the scanner is not the perfect input. Regarding the scanning principle, there is a systematic range difference along the vertical scan direction. This difference introduces additional distance variance and may make continuousness attribute less clear. Instead, the planar distance, or cosine-corrected range measurement, was used. Figure 3 illustrates the range measurement (R) and planar distance (D) against Z-coordinate (Z). The original R-Z data and the employed D-Z data were shown in Figure 3A and Figure 3B respectively, where R, D and Z are in metres.

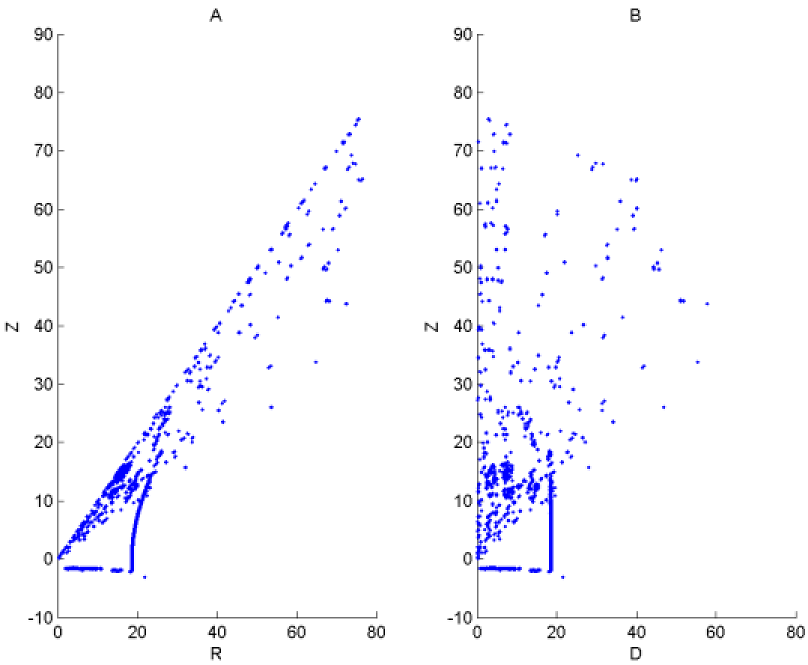

Figure 3. The range (R) and the planar distance (D). (A. the range against the Z value; B. the planar distance against the Z value)

The data matrix of the planar distance and the corresponding scan line continuousness segmentation result is presented in Figure 4A and Figure 4B respectively. In the segmentation result, a unique ID is labelled to each possible trunk.

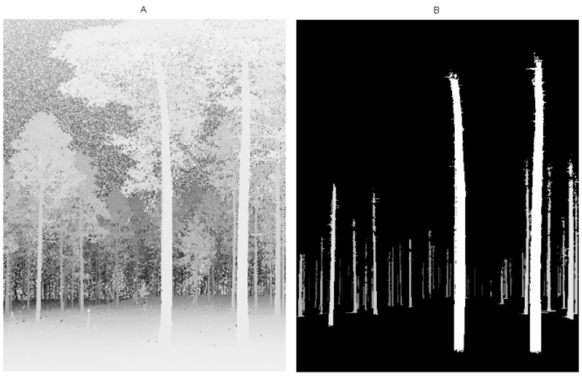

Figure 4. The segmentation input and result. (A. the original data matrix; B. the scan line continuousness segmentation result)

2.4 Tree trunk filtering

In the individual trunk point cloud, some points of branches and ground are still present. For trunk modelling, these points need to be filtered out first. A line-filtering method was developed to identify tree trunk points.

In a vertical scan line, a tree trunk is typically presented as a series of consecutive points, where the variance of planar distances from the scanner is limited. A branch, on the other hand, usually consists of a small number of points that are more shattered. The filtering process of point cloud was carried out in a vertical scan line. First, TLS points, which fell outside the range of twice standard deviation of the mean point distance, were discarded. Secondly, nearly vertically distributed points were identified by distance difference between points next to each other. If the minimum difference was larger than a threshold, the object hit by the scan line is not vertical. A line was then fitted to the point set, and points located far away from the line were removed. The principle is illustrated in Figure 5.

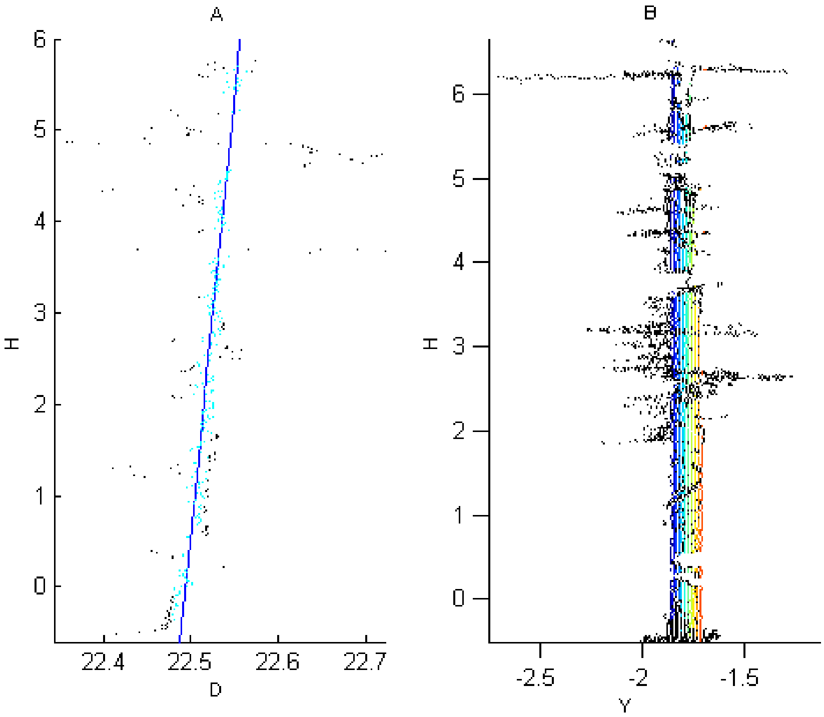

Figure 5: Filtering principle. (A. the TLS points and the fitted line; B. the line filter result)

In Figure 5A, the original TLS points are plotted in black, and the points that are selected as trunk points are in cyan and the fitted line is in blue. In Figure 5B, the line filter result is presented. An individual trunk point cloud is plotted in black, and stem points after the line filtering are presented in colours.

2.5 Tree trunk modelling

The tree trunk was modelled in a two-stage procedure. First, horizontal slices, each 20 cm in height, were selected. Points in the slice were projected to the XY plane. Circles were fitted to the points in the plane. Least square fitting was employed, where the minimized function was the Euclidean distance from points to the circle. Secondly, the statistics of the distribution of the circle centres and radii were studied. Fitted circles were discarded if their positions or radii were not in line with the others. The model consisted of a collection of circles at different heights along the trunk. For this study, the best-fitted circle that was of the least deviation from the fitted radius value was selected for each metre. The centre points of the circles represent the stem curve of the tree. The trunk parameters, e.g., diameters, can then be estimated at any height between the minimum and maximum height of the model by linear interpolation from the closest circles. In this case, the tree location is determined by the lowest circle.

The different stages of the trunk detecting, filtering and modelling process are shown in Figure 6. The original TLS point cloud, the detected trunk, filtered trunk point cloud, circles fitted to the point cloud and circles selected to model the trunk are presented in Figure 6A to 6E respectively.

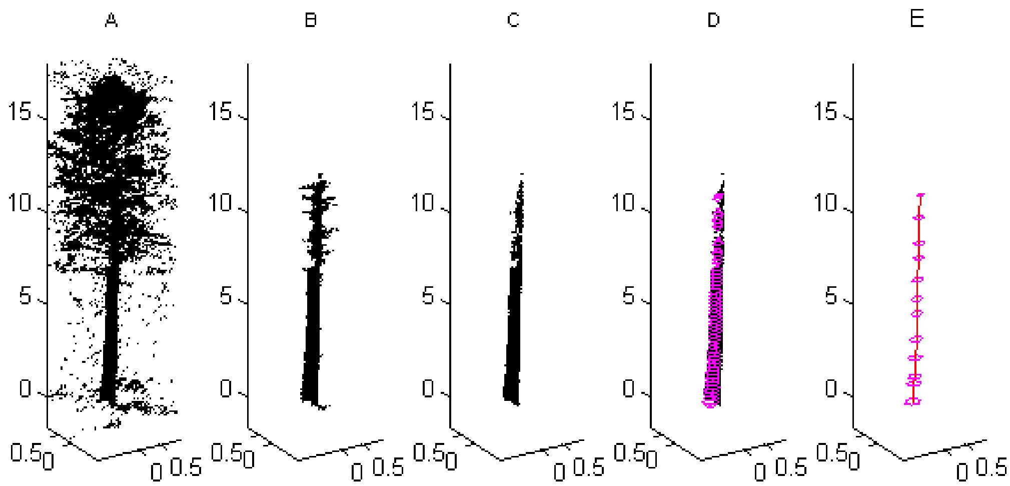

Figure 6: The stages of the tree trunk detecting, filtering and modelling process. (A. The original TLS point cloud; B. the detected trunk point; C. the filtered trunk point; D. circles fitted to the point cloud; E. circles selected to model the trunk)

3. RESULTS

The statistic information of tree trunk mapping is shown in Table 1. In this study, the reference data was interactively interpreted from the same scanning data. Therefore, only one quality measurement, completeness, the ratio between automatic and interactive detection results, was used. In the test, there were also four tree trunks that were located by the automatic procedure but not by the manual detection on the intensity image. They were located at the distance 40 – 60 m from the scanner. The cumulative detection percentage is shown in the two rightmost columns of Table 1.

Table 1: The detecting results at different distances from the scanner.

Distance interval (m)	Manual detection	Automatic detection	Percentage (%)	Distance accumulated (m)	Cumulative percentage (%)
0 – 15	4	4	100		
15 – 20	5	3	60	0 – 20	78
20 – 30	7	6	86	0 – 30	81
30 – 40	17	15	88	0 – 40	85
40 – 50	9	9	100	0 – 50	88
50 – 60	10	7	70	0 – 60	85
Total	52	44	85		

Figure 7 illustrates the tree location mapping result. The scanner is at the origin of the local coordinate system, marked by a plus sign. Automatically detected and modelled trunks are marked by black crosses and plus signs respectively. Manually detected trunks are marked by circles; red circles are trees of normal size and green circles represent very thin trunks that consisted of only a few vertical scan lines. Therefore, a black asterisk inside a circle denotes a trunk successfully detected and modelled by the automatic procedure; an empty circle denotes a trunk that is missed by automatic detection; a black asterisk alone is a trunk that was not found manually by the operator; and a black cross indicates a tree trunk that is automatically found but not successfully modelled. The tree trunks that were not modelled were typically those showing a small proportion of the whole trunk in the data set due to either the heavily occluded by other tree trunks or the long distance from the scanning position.

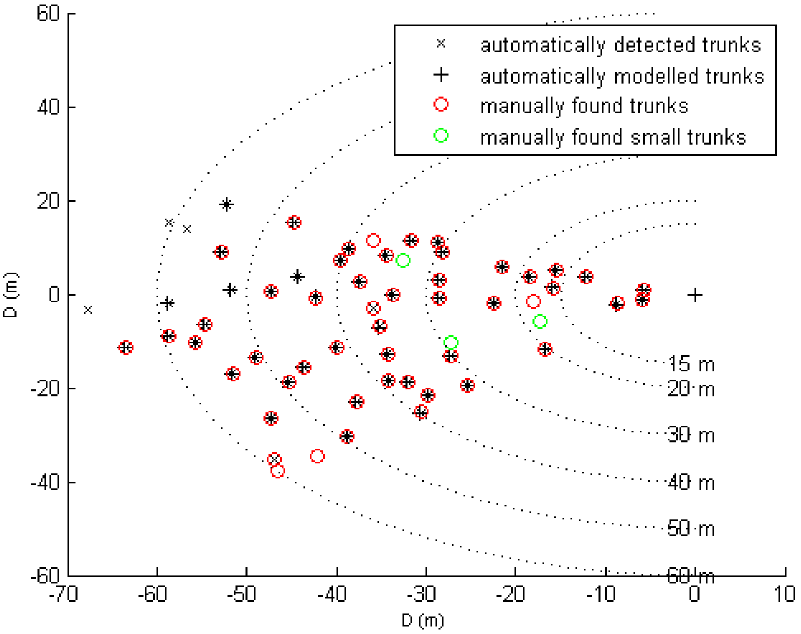

Figure 7: The results of tree trunk mapping in a one-layer forest.

4. DISCUSSION AND CONCLUSION

TLS data is anticipated, in the near future, to provide tree-wise and plot-wise reference for ALS forest assessment, while the point density of ALS is increasing and the individual-tree-based forest inventory technique is evolving towards a more practical use. Among different parameters, the number of stem, plot-wise basal area, DBH and location of each tree trunk and centre of the crown are expected to be the most important parameters of these sample plots.

In this paper, an automatic tree location mapping algorithm of the single-scan TLS data in typical economical forest environment is presented. The proposed method has the following features.

First, the segmentation is performed in the 2D space but the result is similar to that in the 3D space. The laser-illustrated points, close to each other in the 3D space, located also near to each other in the 2D representation of the scanned scene. By the pixel position in the scan lines, the distance measurement, and the combining groups in two directions, the segmentation in the 2D space functions similarly to that in the 3D space by XYZ coordinates. Therefore, the algorithm is computationally effective, as the computation is performed in lower spatial dimension. For instance, the 3D distance calculation is replaced by the planar distance comparison and the profile intersection searching.

Secondly, the procedure is performed on the original scanning point cloud, where no interpretation or smoothing is required. At some stage, the processing is performed in the image space. But, the procedure depends mainly on original spatial measurements or their equalities. The data matrix is employed as a data structure. In that sense, the method is a point cloud processing technique.

Thirdly, the proposed approach can be employed in data sets collected by different type of scanners for the tree location mapping. The method is developed based on the scanning mechanism and range measurements. It does not depend on any instrument-specific measurements, e.g., waveform or spectrum. The exact measurement principles vary among scanners. However, the step-by-step sampling mechanism is the common procedure, which gives row and column information after scanning, and the range is the measurement provided by all scanners. In addition, the method does not have specific requirements for the local terrain. It can be applied in forest with different terrains.

The results of this study show that in a one-storey pine forest, it is possible to automatically detect and model trees that are visible to the scanner and within some predetermined distance from the scanner. The automatically tree trunk detection percentage was 85% up to 60 m range from the scanner. According to this result, the achievable plot size for a single-scan TLS measurement could be larger than the plot sizes typically used in manual plot measurements if the point density is high enough for detecting and modelling, taking into account the occlusion issue in forest environment. Reference measurements from larger plots will be needed to validate this assumption.

The limitation of the method is, however, that it is designed for single-scan TLS data and based on the image structure. The main disadvantage of the application of single-scan TLS in the forest inventory is the occlusion effect. The occlusion happens when laser beams are reflected from foreground objects, e.g., stems and canopies, while objects behind are completely or partially missed in the point cloud. It is impossible or very difficult to detect objects standing fully in shadow or heavily occluded. It is reported that around 10 percent of the trunk are not available in the single-scan data in the sample plot with 10 meters radius (Liang et. al., 2011). The missed trunks can be located by scans from other direction and registration at the object-level. Further experiments are needed to test this procedure.

The tree trunk location mapping algorithm presented and analysed in this paper is an automatic procedure. It requires neither the prior knowledge about the local terrain nor instrument-specific measurements. Future developments lie in the improvement of the trunk modelling method, to improve the performance when the point density is low, large occlusion area is present and the trunk shape is complex. In addition to plot-wise tree location mapping, this procedure also provides a sound basis for other applications, such as the retrieval of stem curve, DBH, and open stem height, where the trunk model serves as the input data.

5. ACKNOWLEDGEMENTS

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