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LOCATING AND PARAMETER RETRIEVAL OF INDIVIDUAL TREES FROM TERRESTRIAL LASER SCANNER DATA

Thesis of (PhD) dissertation

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Aims and scope

Terrestrial laser scanning is an active remote sensing technique operating from fixed ground based position and using laser range finding with high measuring frequency to obtain directly 3D coordinates (and optionally reflectance data) of high spatial density from object surfaces. The recorded data allows for the creation of structural model of the target objects. Laser scanner data captured in forested environment can be processed using automatic methods, although the reliability and accuracy of the results strongly depend on the stand characteristics. Terrestrial laser scanning is a prospective means for the objective retrieval of stand parameters in Hungarian forests. However, for its effective and extensive use, special algorithms are needed that have been developed considering the regional stand characteristics.

The dissertation introduces the description of algorithms developed by the author with the goal of locating tree positions and retrieving quantitative attributes (stem diameter at breast height (DBH), total tree height and crown projection area) in a highly automated manner from terrestrial laser scanner data. The algorithms support the processing of laser scanner point clouds captured in forested environments without any information on the thematic categories of the recorded objects.

The algorithms address the following issues:

1. Elimination of laser scanner data captured from vegetation, but being irrelevant in respect of tree mapping
2. Classification of stem point measurements i.e. delineating and assigning them to the corresponding tree (tree detection)
3. Creation of the physical model of the tree surface that can be realized as a parametric model of the stem cross-section or as a 3D grid model of the complete tree structure
4. Derivation of stem locations and quantitative tree metrics from the models

These goals have been achieved through vector, raster and 3D grid (so-called voxel) data structure. The author implemented the proposed algorithms in the ANSI C programming language, resulting in a package of 32-bit console applications. The performance of the algorithms concerning the reliability and estimation accuracy was validated against in-situ reference measurements from Hungarian stands with close-to-nature conditions.

Brief introduction of the algorithms

1. Filtering of irrelevant data

Point measurements reflected from the low vegetation, twigs, as well as ghost points resulted from measurement errors are irrelevant from the viewpoint of tree mapping. Irrelevant data have adverse effect on the reliability of stem detection therefore, they must be eliminated through filtering. Two methods have been developed; a two and a three-dimensional one. Both require the conversion of the point cloud into a regular grid data structure. The 2D filtering method analyses the coexistence of data patterns at the level of cells and local regions between overlaying rasters of horizontal point cloud sections. The filtering concept implies that the spatial arrangement of the irrelevant data is irregular and the patterns are different in distinct heights sections. The 3D filtering is based on an asymmetric structuring element that specifies the possible region of space for the stem surface points. The asymmetric shape results in an anisotropic filtering effect that favours the preservation of point measurements reflected from vertically elongated surfaces, such as stems. The filtering routines were tested on the data source used for the subsequent stem detections. The 2D filtering eliminated 86.9% of the cells, which played a key role in the success of stem detection. The 3D filtering proved efficient and effective for the extraction of juvenile trees in regeneration patches, yielding reduction in data in the range of 41.2–63.2%. The structuring element devoted to the elimination of irrelevant data can be utilized alternatively to select stem point measurements.

2. Stem detection by clustering the point cloud

The stem detection assumes that the point measurements reflected from the tree surface are grouped into clusters showing locally high data density. Delineation of the point clusters as the representation of potential stems is achieved by partitioning the horizontal section of the point cloud. In contrast to the classic partitioning routines, the number of clusters is unknown in advance so the maximum cluster diameter is specified as an input parameter that can be estimated with the stem size of the expected largest tree. The stem clusters are selected with the comparison of circle parameters resembling the shape of the stem cross-sections in distinct height sections. An additional routine is proposed for the computation of circle parameters according to the concept of least-squares adjustment. The routine needs no linearization of the object function; thus; it is less sensible to the accuracy of the initial parameter values. As a result, it is possible to apply the circle fit for stems with asymmetric data pattern (e.g. in case of partially occluded trees). The algorithm was validated on a data set recorded from a single scanning position with regard to the trees visible from the vantage point. The ratio of correct detections was 76.9%, with a misclassification rate of 4.6%. The bias of the DBH estimates was –1.3 cm, with RMSE of ±2.1 cm.

3. Stem detection by means of image objects

The algorithm is aimed at the detection of trees with data discontinuity and the reduction of the negative effects of low vegetation and of branches on the DBH estimation. The fundamental elements of the processing are image objects composed by the union of disconnected image regions with a predefined buffer zone. A shape index was introduced for the recognition of stems quantifying the circularity of the image objects. Stem cross-sections are frequently represented by multiple (disconnected) image objects, especially in the presence of branches or in the case of merged scans. Coherent image objects are aggregated on a higher object level, which provides complete and unambiguous representation of the stem cross-sections. The cells of the stem surface are distinguished from those resulting from interference from branches, in order to improve the accuracy of the DBH estimates. The algorithm was validated by the processing of an especially large data set of 38 laser scans with 1,561 sample trees. The ratio of correct detections was 70.5%; the ratio of misclassifications was 20.6%. The bias of the DBH estimates was –0.9 cm, with RMSE of ±2.5 cm. Stem detection proved reliable for trees with DBH exceeding the value of 25 cm.

4. Detection of juvenile trees

The automatic mapping of juvenile trees (saplings) requires different object detection approaches compared to the mature trees. The contiguous regions in the voxel space, i.e. in a 3D regular grid, are generalized by Dijkstra’s minimum spanning tree routine that removes the data from branches and results in the vertical axis of the stems. The high tree density within the regrowth patches induces partial occlusion of stems, which necessitates the aggregation of the corresponding vertical axes (fragments). An optimization procedure was developed for the selection of the matching fragments considering the shape, size and separation of the resulting disconnected image object with three finite parameters. The procedure tends to produce models of straight axis, maximum size and minimum degree of fragmentation, which show analogy with the shape of juvenile tree stems. Three sample quadrates representing different structural conditions were used for the validation. In comparison to the tree positions located by visual interpretation, the ratios of correct detections were found in the range of 79.3–90.2%. The misclassification rate, relative to the correct detections ranged from 9.8 to 25.7%. Out of the investigated site properties, stem density had the principal impact on performance, while the effect of branching frequency was less relevant.

5. Modelling of mature trees in the voxel space

This algorithm reveals the complete structure of mature trees through 3D disconnected voxel objects, enabling the direct retrieval of tree height and crown projection area. The initial voxels for the region growing (seeds) are identified in the vertical interval ranging from the top of the low vegetation up the canopy base to avoid the misclassification of stem voxels. The same asymmetric structuring element is used for the highlighting of stem voxels as was applied for filtering of irrelevant data. The creation of contiguous voxel objects representing the stem from the complete tree is achieved by a simultaneous region growing procedure starting from the seeds, which has the capacity to delineate individual trees even if there is physical connection between their branches. The regions in the upper crown are fragmented by data gaps resulting in their separation from the stem object. These branches are assigned to the closest stem, where the distance between the objects is specified with regard to the assumed nodal end of the branch. The total tree height is estimated directly from the relative elevation of the top voxel, while the crown projection area is represented by the horizontal convex hull of the crown. The validation of the tree parameter retrieval was carried out using the merged data set of four laser scans. In comparison to the results derived from visual interpretation, the bias of the height estimates was –0.1–0.5 m, with RMSE of ±0.2–0.6 m. The relative bias of the crown projection area estimates were ranged from –2.5 to 12.3%, with RMSE of ±32.0–44.3% in relation to species groups and canopy layers.

Practical aspects

The proposed algorithms constitute a complete process chain, supporting single or multiple scanning modes as well as having capacity to locate tree positions and to assess additional tree metrics (DBH, tree height, crown projection area) over wide range of structural stand characteristics. The algorithms are appropriate for maintaining sample-area-based inventory and the mapping of complete forest stands, irrespective of the technical parameters of the scanning and they offer automatic, repeatable and objective data processing. The accuracy of the estimated DBH and tree height is comparable to the results generated by traditional devices. In addition to these two standard inventory parameters, the algorithms provide further outcomes, such as tree maps and models of the complete tree structure. Special attention was paid to the suitability in close-to-nature stand conditions. The algorithms provide solutions for the reduction of the adverse effects of low vegetation, for the mapping of juvenile trees in regrowth patches and for parameter retrieval in mixed stands with multiple canopy layers. The author sees the following potential fields of application:

1. Forest inventory with stratification supported by remote sensing as the stem maps and tree attributes derived from the terrestrial laser scanner data in sample plots may be used for the calibration of smaller scale data, such as airborne laser scanning or satellite images.

2. Ecological studies and simulation of forest growth require accurate tree locations and crown metrics to account for interactions at the individual level.

3. Civil engineers take the advantage of accurate tree locations and the visualization of 3D structural models in the course of construction planning in forested areas.

Thesis

1. Specific algorithms have been developed to filter the data that are irrelevant with regard to tree mapping and modelling. The algorithms support the automatic mapping of trees in the presence of low vegetation as well as in regrowth patches.

2. A partitioning method has been proposed for locating stem positions and DBH estimation from the horizontal section of the point cloud data. It has been proven that the algorithm is an efficient tool in the mapping of even-aged stands with sparse low vegetation.

3. A raster-based method has been developed that detects tree positions and delivers cross-sectional stem models in the presence of low vegetation following the aggregation of disconnected image objects in a two-level hierarchic structure. Geometric relations are used for selecting stem surface measurements to improve the accuracy of DBH estimates.

4. A voxel-based method has been developed for detecting and reconstructing juvenile trees in regrowth patches. The algorithm aggregates the tree fragments in the 3D voxel space through a parametric optimization procedure and delivers the tree positions and axes of stems as a disconnected set of generalized image objects.

5. An algorithm has been proposed for the creation of complete 3D structural models of conifers and deciduous trees in the voxel space. The delineation of individuals was achieved through a simultaneous region growing procedure that enables unambiguous segmentation even in case of multiple stems and high canopy closure. The models consider the data discontinuity in the upper crown region; thus, they provide an apparent basis for the estimation of tree height and crown projection area in multi-layered stands.

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