VEGETATION MODELLING BASED ON TLS DATA FOR ROUGHNESS COEFFICIENT ESTIMATION IN RIVER VALLEY

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ABSTRACT:

Many environmental studies such as generation of hydrodynamic models, that are tools for risk management, require information about vegetation conditions. The description of vegetation from the hydraulic modelling point of view should include type, distribution and arrangement of existing plants. Geometric parameters of plants can be determined on the basis of laser scanning data. Terrestrial laser scanning (TLS) allows to determine precisely not only the external shape of the plant, but the geometry of individual branches as well. A method for macro and micro-structure estimation of a single shrub is presented in this paper. The data used in the research were measured with Leica ScanStation II. In the macro-structural approach, where the plant is considered as a compact solid, it is important to choose those measurement points that represent the surfaces of the plant. To achieve better matching to the non-convex parts of the hull the use of a multi-stage solid generation procedure is proposed. In this approach points are divided into segments with common edges. The method assumes that the plant is divided along the z axis into segments of a given width. First, points from one segment are projected onto the division plane. Then, 2D convex hull is generated for all the points. Finally, selected points (again in 3D space) are used for 3D convex hull generation. In order to define the geometry of vegetation the micro-structure procedure is supplemented by the segmentation algorithm to split points into groups, which form one branch. To verify the accuracy, the total surface area and the total shrub volume of branches calculated for individual variants were compared with the total surface area and volume derived from the direct measurements. Additionally, the qualitative analysis was also carried out.

1 INTRODUCTION

In the recent years the intensity of floods, occurring often in the certain part of the world, increased significantly causing huge destruction and economical loss. An important tool of disaster protection and risk assessment in such regions is hydrodynamic modelling. For the efficient hydrodynamic modelling detailed Digital Elevation Model (DTM) of a river valley is required. The DTM also has to incorporate information about vegetation cover on the area endangered by flood. This information is indispensable for the estimation of roughness coefficients, which are very significant parameters for generation of hydrodynamic models and for flood modelling. A river valley area is usually cover with shrubbery. The description of vegetation from the hydraulic modelling point of view should include type, distribution and arrangement of existing plants.

Geometric parameters of plants can be determined based on laser scanning data. Terrestrial laser scanning (TLS) enables to determine precisely not only the external shape of a plant but the geometry of individual branches as well.

Vegetation modelling from laser scanning point clouds (especially trees) is a hot topic in numerous environmental studies in last years. The quality of 3D point clouds generated by laser scanners and the efficiency of this technique, make TLS also an attractive tool for forest inventory. The geometric parameters, such as tree heights and breast height diameters, are determined by interactive measurement in 3D point clouds (Thies and Spiecker, 2004) or by automatic detection of trees and followed by subsequent determination of the aforementioned geometric parameters (Bienert et al., 2006). They present an algorithm to detect trees in a horizontal cross section through a 3D point cloud. Using the knowledge of an approximate position and diameter returned by the tree detection process the stem profile at different height intervals was determined using least squares circle fitting algorithm. (Pfeifer and Winterhalder, 2004) present a method to estimate cross section of tree branches and stems using free-form curves. This model describes branch surfaces with a sequence of overlapping cylinders. In orthogonal slices to these cylinder axes points selected from data set are approximated with B-splines. Based on this, the measurement of branch ovality was performed.

In the other recent papers a new area of using TLS data and 3D modelling is shown. An example is using the 3D structure to present the tree orchards (Rosell et al., 2009). The geometrical parameters of trees were measured interactively in point clouds using standard CAD software. For some applications, e.g. estimating leaf areas of individual trees (Rosell et al., 2009), a macrostructural model of tree can be useful.

In this paper a method for macrostructural and microstructural modelling of single shrub and small tree is presented. The macrostructural model describes a shrub using TLS points that make up the contour of a plant in 3D space. The microstructural model describes a branch topology and geometry of single branches. In both cases a convex-hull algorithm for sliced point cloud data is used. The segmentation is preformed along the z axis. In the next step the convex-hulls in particular slices are integrated into one 3D model. The presented algorithm was tested using TLS data taken from artificial and real shrubs. The point clouds were obtained using Leica ScanStation II scanner. The comparison of geometrical shrub parameters, derived from the model and parameters obtained by direct measurement, is also given in the paper. The method was developed for roughness coefficient estimation in hydrodynamic modelling. It can be used to estimate the relevant parameters for forest inventory as well.

2 DETERMINATION OF THE VEGATATION GEOMETRIC PARAMETERS FOR A CALCULATION OF THE FLOW CAPACITY IN A RIVER BED

Hydraulic parameters of a river bed covered by vegetation can be determined by treating plants as the impenetrable elements for the water stream. This attitude is applied for the areas that are covered by singular trees and shrubs. A span a_x, a_y and a diameter d_p are the indispensable parameters for roughness coefficient determination (Fig 1). In such case it is crucial to assess the volume of a solid figure and the area described by its shape. When the shrub structure is compact the attitude is inadequate and a microstructure of bushes is investigated instead. The microstructural model treats plants as the impenetrable elements and bases on an average diameter d_p and a span a_x, a_y of branches. Resistance coefficient of a group of plants is calculated using the following dependency:

$$\lambda_p = C_{WR} \frac{4 d_p h cos\alpha}{a_x a_y}, \qquad (1)$$

where: h - flow depth,
α - inclination angle of the area's longitudinal profile.

The C_{WR} coefficient according to Rickert (Rickert, 1986):

$$C_{WR} = \left[1.1 + 2.3\frac{d_p}{a_y}\right]\left[0.6 + 0.5log\left(\frac{a_x}{a_y}\right)\right] + 2\left[\frac{1}{1-\frac{d_p}{a_y}} - 1\right] \qquad (2)$$

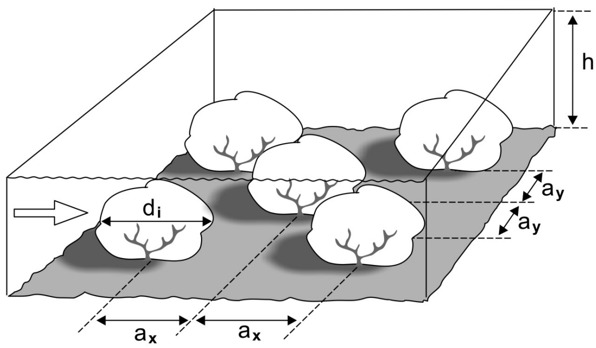

Figure 1: The parameterization of the vegetation geometric features for the determination of flow resistance

The described calculation methodology is applied in practice; however, it significantly simplifies the stated problem. On the contrary, the numerical model of a solid figure or a plant structure allows to determine an area and a wetted perimeter of each plant. It enables as well to consider the geometry of a plant in two- or three- dimensional hydrodynamic model. Such attitude is not practically applied yet, nevertheless it is discussed in the literature (Kaluza et al., 2009, Tymkow, 2009) and its initiating in the future is probable.

3 SHRUB MODELS BASED ON INTEGRATED CONVEX HULL ALGORITHM

Depending on the scanning resolution, vegetation species and the occurrence of foliage, many authors propose different attitudes towards modelling and reconstruction of the plant geometry. Generally, there are two types of models. In case of calculation of the hydraulic features for flow modelling the models can be referred to micro and macrostructural approach. The essential step for the construction of the macrostructural model is proper choice of the points that make up the contour of a plant. Those models are applied when their microstructural counterparts are unnecessary or impossible to be specified. For microstructural models a branch topology can be determined using, e.g. graph theory (Bucksch and van Wageningen, 2006). Then, the obtained microstructural model is used to create a polyhedral model by fitting in geometric primitives like cylinders e.g. (Pfeifer and Winterhalder, 2004).

A simple algorithm for modelling micro and macrostructure of single shrub (small tree) is presented below. In both cases point cloud segmentation along z axis and a convex-hull algorithm are used.

3.1 2D-3D convex hull algorithm

Convex polyhedral is a 3D natural generalization of a closed and convex 2D polygon. The implementation of algorithm for convex hull determination in 3D space is a complex task. The details can be found in numerous papers, e.g. (O'Rourke, 1988). The application of the aforementioned algorithm in polyhedral modelling is known since a long time (Cluzeau et al., 1995). Unfortunately, treating the whole solid figure of a plant as a convex one leads to substantial simplification of its complexity, hence to the incorrect estimation of geometry. In order to improve the fitting to the not convex fragments of a plant the attitude proposed here is a multi-steps variant of the determination of a solid figure. It is based on the partitioning of the point cloud by the planes that are parallel to the XY plane. As a result the segments with common adjoining edges are obtained. Each segment is created as an independent convex hull, nevertheless, the integration of the segments is not integral. Merging the segments is executed by choosing the points of a 2D convex hull on the lower level and considering them as adjoining points of the neighboring segments. The models (before and after integration) obtained from a small point cloud are presented in the Fig. 2.

Figure 2: Convex polyhedrals before and after integration

The parameter that has to be set at the preliminary stage of the method is a distance between the individual planes of the partitioning. In order to provide common adjoining areas of segments the procedure of the single segment modelling contains the following steps:

- points that belong to the one segment are projected on the partitioning plane,
- for all the points in the segment the 2D convex hull is determined,
- points selected in the previous step and supplemented by z coordinate form the lower border of a 3D convex hull of a segment,
- 3D convex hull is created, with an upper border determined by the points also extracted using 2D convex hull algorithm,
- the procedure is continued for next level till last one.

The procedure of 2D convex hull determination is based on Graham algorithm (O'Rourke, 1988).

The process applied for microstructural model is very similar. The first difference is that the segmentation of the point cloud has to be done on each level, resulting in clusters that potentially present one branch. The next one is that the integration is carried out from the highest level to the lowest. Segmentation algorithm is based on the simple unsupervised classification considering nearest neighboring. As a partition coefficient it takes the maximum width of a branch, set at the preliminary stage. The simplified procedure reads as follows:

- each of the point in a segment determines the center of the mass of the next branch,
- one point is selected randomly,
- the nearest neighbor of the selected point is found,
- if the distance to the nearest point is smaller then the established maximum width of a branch, it is assumed that the both points belong to one branch, which is now represented by the center of the mass of the point set. Otherwise, the integration will not be executed,
- next point is drawn and the merging procedure is repeated until there is no segments that should be integrated.

The exemplary projection of a point cloud representing one segment, with marked mass center of each branch is displayed in the Fig. 3

The above mentioned procedure is inadequate for the modelling of big trees because of their significant difference of branch width. However, in case of shrubby vegetation it returns good results. The following part of the computation is analogues to the macrostructural procedure. The convex hulls are computed for each branch in each segment. Next, the nearest segments are integrated with each other, starting from the top and ending with the lowest polyhedral. In that way the topology of branches connections is determined and the continuity of a solid figure of a plant is maintained. Area and volume of a plant is calculated based on the model geometry.

Certainly, the proper choice of an optimal width of a segment has a great impact on the modelling process and the final values of the surface parameters and volumes. Too big threshold leads to simplify a model. The lower limit of a threshold values is determined by scanning resolution - in order to create 3D convex hull at least four points are requested.

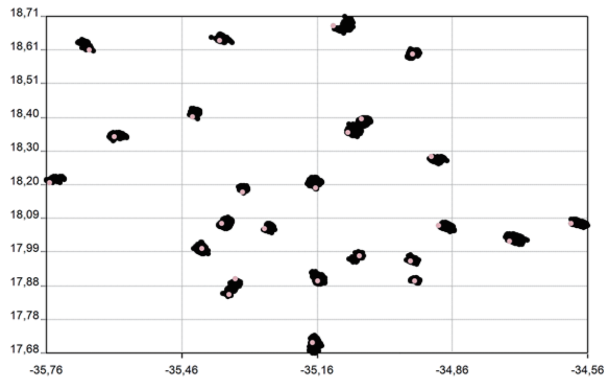

Figure 3: An exemplary projection on XY plane of point cloud for one segment. The centers of mass that represents branches are marked in color.

4 TESTS AND RESULTS

4.1 Data acquisition

In order to assess quality of estimated geometrical parameters, a physical model was created that represents simplified shape of a shrub. In order to get the reference values the model was annually measured using the micro- and macrostructural approach. Macrostructural survey was based on plant radius measured by a measuring tape on three levels in two parallel directions. The results were used to interpolate GRID model of a plant shape with approximately elliptical cross section (Fig. 4. Microstructural survey was performed by measuring diameter of each branch at three places by a slide caliper. Ultimately, the model was measured by a scanner Leica ScanStation II. The measurement was executed using two stand points. The scanning resolution was equaled 3-4 mm.

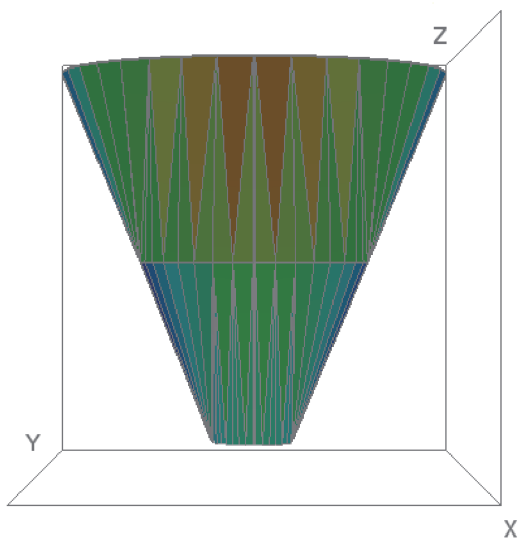

Figure 4: Visualization of macrostructural GRID model of artificial plant measured by a measuring tape

4.2 Modelling

Based on the point cloud, thirteen macro- and eight microstructural models were created. The models were developed for average thickness of a segment within an interval: 3,8 − 10 cm. Figure 5 presents an exemplary models of the plant.

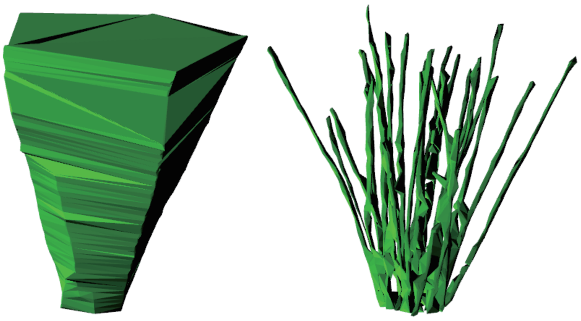

Figure 5: Visualization of macro- and microstructural models of an artificial shrub

Reference data and measures computed on the basis of the 3D models have served for the assessment of variety of their accuracy, depending on width of a segment (c.f. 6 and 7). The Figure

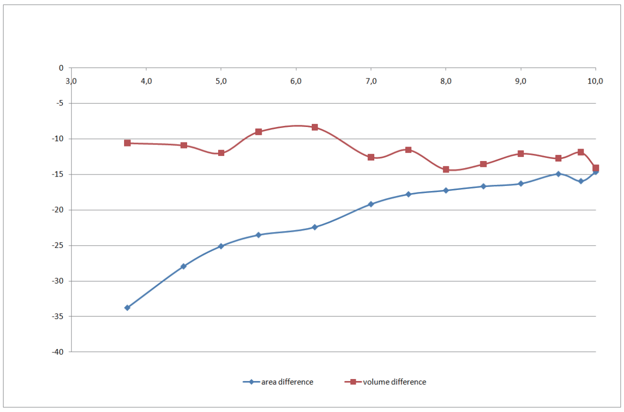

Figure 6: Area and volume - comparison of differences between values obtained from a macrostructural model and values measured directly

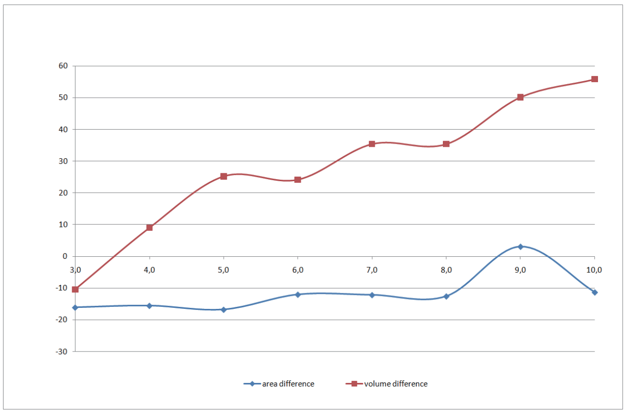

Figure 7: Area and volume - comparison of differences between values obtained from a microstructural model and values measured directly

6 shows that both, area and volumes, are under-assessed with relation to the reference measures. Average error is equaled to 20% for area and 13% for volume. The best results were achieved for the segment width 9 − 10 cm, in case of area computation, and 5,5 − 6 cm for volume computation. In these cases the differences are equaled to 15% and 9%, respectively. The reference survey is significantly simplified, though and cannot be treated as an error-less. For microstructural approach the discrepancies are similar for area estimation and much higher for volume estimation. Moreover, the volume rises with increasing thickness of the segment.

In order to evaluate qualitative assessment of modelling a real plant was scanned. Figure 8 presents the acquired point cloud, Fig. 9 and Fig. 10 display the created models. Visual assessment shows that the model is sufficient enough for hydrodynamic calculation; nevertheless, there are few topological mistakes.

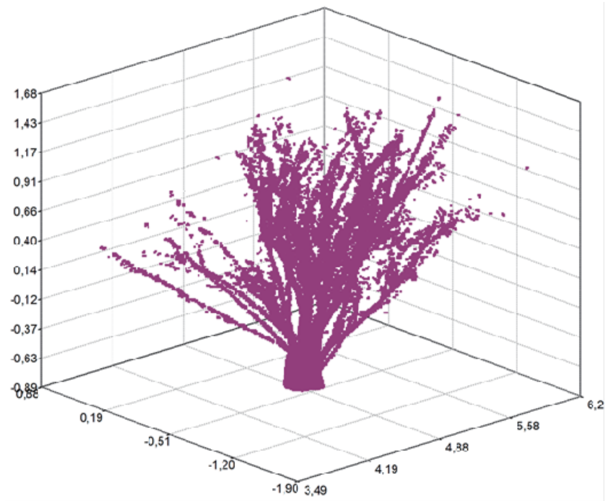

Figure 8: Visualization of a point cloud and a microstructural model of a real shrub

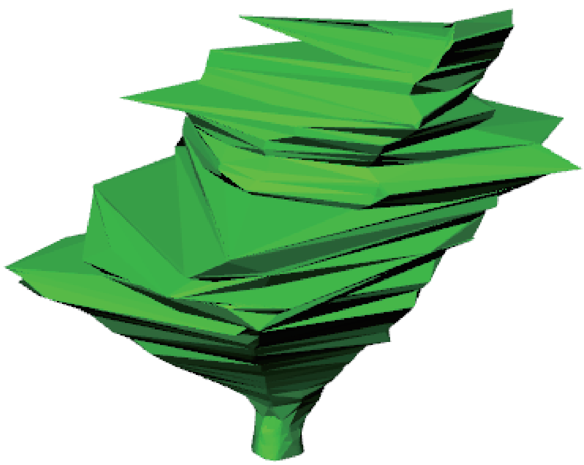

Figure 9: Visualization of a macrostructural model of a real shrub

5 CONCLUSIONS AND FUTURE WORK

The paper presents a method for a construction of micro- and macrostructural real models of shrubbery vegetation. The ap-

Figure 10: Visualization of a microstructural model of a real shrub

proach is based on convex hull algorithm. Laser scanning data are portioned into slices along the planes perpendicular to the z axis. Then, convex hull is determined for each slice. Finally, all convex hulls are merged into one macrostructural model. For a construction of a microstructural model points of each slice are segmented into clusters. This process is executed in order to determine the points that describe singular branches. The critical parameter is width of a slice. Too high threshold leads to simplification of a model. The lower limit of threshold values is determined by scanning resolution - in order to create 3D convex hull at least four points are requested. Quality assessment of branch area and volume evaluation, carried out for a model proves that the results are under-estimated – smaller of $10 - 20\%$. It is caused by simplification of a numeric model and reference measurements.

A microstructural model also features some topological mistakes. Avoiding them will be the aim of future work. The algorithm cannot be applied to large tree modelling (considerable differences between branch thicknesses within one model) because of assumed maximum width of a branch. The algorithm is quite simple and achieves good efficiency.

The presented method of a shrub modelling was developed for determination of roughness coefficient in river valleys, in connection with hydrodynamic modelling. The obtained results are satisfactory. The method can be applied as well in forest inventory (in order to compute geometrical parameter of lower vegetation), agriculture and orchanding (determination of various parameters of plants and fruit bushes).

REFERENCES

Bienert, A., Maas, H.-G. and Scheller, S., 2006. Analysis of the information content of terrestrial laserscanner point clouds for the automatic determination of forest inventory parameters. ISPRS WG VIII/11 & EARSeL joint Conference '3D Remote Sensing in Forestry', Vienna, 14-15 February pp. 1–6.

Bucksch, A. and van Wageningen, H. A., 2006. Skeletonization and segmentation of point clouds using octrees and graph theory. Vol. XXXVI, pp. 1–6.

Cluzeau, C., Dupouey, J. L. and Courbaud, B., 1995. Polyhedral representation of crown shape. a geometric tool for growth modelling. Annals of Forest Science 36, pp. 297–306.

Kaluza, T., Tymkow, P. and Strzelinski, P., 2009. Using of hemispherical and lidar photos in investigation of structure of river bank riparian scubs. Reports of the 12th European Weed Research Society (EWRS) International Symposium on Aquatic Weeds, The Finnish Environment Institute, Jyvaskyla, Finland, August 24-28 p. 43.

O'Rourke, J., 1988. Computional Geometry in C. Cambridge University Press.

Pfeifer, N. and Winterhalder, D., 2004. Modelling of tree cross sections from terrestrial laser-scanning data with free-form curves. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 36, pp. 76–81.

Rickert, K., 1986. Der einfluss von geholzen auf abflussverhalten in fliessgewassern. mitteilungen. Technical Report Heft 61, Institunt fur Wasserwirtschaft, Hydrologie und Landwirtschaftlichen Wasserbau der Universitat Hannover.

Rosell, J. R., Llorens, J., Sanz, R., Arno, J., Ribes-Dasi, M., Masip, J., Escola, A., Camp, F., Solanelles, F., Gracia, F., Gil, E. and Val, L., 2009. Obtaining the three-dimensional structure of tree orchards from remote 2d terrestrial lidar scanning. Agricultural and Forest Meteorology 149(2009), pp. 1505–1515.

Thies, M. and Spiecker, H., 2004. Evaluation and future prospects of terrestrial laser scanning for standardized forest inventories. Inernational Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVI, PART 8/W2, pp. 192–197.

Tymkow, P., 2009. Application of photogrammetric and remote sensing methods for identification of roughness coefficients of high water flow in the river valleys. Wydawnictwo Uniwersytetu Przyrodniczego we Wroclawiu.