

Application of a 3D Laser scanning device to acquire the structure of whole root systems- A pilot study

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Introduction

The analysis of entire root systems in tree stability studies as well as the estimation their role in the CO₂ budget of Swiss forests is confronted with multifaceted problems. Whereas the dimensions of the above ground parts of a tree are more or less easy to determine, measuring root dimensions and especially their spread is rather difficult.

Tree stability towards mechanical impacts has been research topics in forestry and tree-ring research for more than a century (e.g., Hegler 1893). Research has focused on growth reactions on a micro- and macroscopic level mostly due to the influence of wind (Jacobs 1954). Since then, various species-specific reaction mechanisms in stems due to mechanical stress have been analysed and used to date geomorphic processes (Alestalo 1971, Shroder 1980, Wiles et al. 1996, Gärtner et al. 2004). More recently, the focus has been set on physical parameters respecting the distribution of various mechanical pressures as well as the mechanical properties of stem wood (Burgert et al. 2004). Apart from studying specific tree parameters (e.g., tree and stem height, crown area) the effect of stand density and soil properties, which are important factors for the development of root systems are of special interest (Peltola et al. 2000) because tree anchorage is crucial for stability. Mattheck et al. (1997) have shown, that an optimised design of root systems would ensure an equal distribution of acting forces along the roots. Consequently, a uniform distribution of coarse roots around the stem might be expected on a shallow site with homogeneous site conditions. Root system development is controlled by various factors, which are determined by the main functions of a roots system: (i) anchorage, (ii) absorption of water and nutrients and (iii) transport of these substances to the stem (Sitte et al. 1998). Normally, these functions would be equally distributed within the root system, but specialisations of single roots due to e.g., varying soil properties specialisations frequently occur resulting in the dominance of one of the main functions. As a consequence a symmetric spread of roots rarely occurs and even ring-width variations along single roots are highly variable. Ring-width measurements and analysis of anatomical variations are techniques which have been applied to reveal the development and mechanical properties of a root at a given section (Gärtner et al. 2001, Gärtner 2003). For the analysis of the full complexity of a root system, it is desirable to attribute the properties of these sections to their position within the system. Due to the complexity of bifurcations within a root system, this mapping and the following analysis is highly complicated, often even impossible (Gärtner and Bräker 2004). Consequently, to

realise a detailed analysis of a whole root system, a high resolution model of the root structure is required. This model has to be even more detailed than it is realized using magnetic field devices, used to measure and represent root lengths and bifurcations in three-dimensional space (Nicoll and Ray 1996, Sinoquet and Rivet 1997, Danjon et al 1999, Di Iorio et al. 2005). At the Swiss Federal Research Institute WSL a ground based 3D- laser scanner was used for the first time to generate a three dimensional model of an exposed root system. The study presented here was accomplished to investigate the opportunities and limitations of this technology.

Material and methods

The work started on a separated part of the root system of a mature beech (Fig. 1), which was exposed for root biomass analysis (Gärtner and Bräker 2004).



Figure 1: Removal of the root system of a mature beech for further analysis in the lab. One part of the root system was used for the scanning procedure (lower picture)

This part consisted of two main roots (length 1.3 m) with hundreds of small lateral roots, many of them showing anastomosis. This rather dense network was chosen to identify problems resulting from expected shadowing effects caused by mutual maskings of the single roots within the complex system. For this pilot study, a Cyrax ® HDS2500 scan device was used. It has a maximum 40° x 40° field-of-view (Leica Geosystems 2003), a single-point range accuracy of +/- 4mm, angular accuracies of +/- 60 micro-radians, and a beam spot size of 6mm from 0-50m range. Minimum vertical and horizontal point-to-point measurement spacing is 0.25mm referred to a distance of 50m. The root was scanned by 1.000 points/column and 1.000 points /row. The resulting data file contains 1.000.000 data points

(xyz-coordinates) representing the surface of the roots visible from the position of the scanner. However, all areas behind these visible surfaces do not deliver data (shadowing effect, Fig. 2). To prevent this effect, the root system was scanned from different positions to acquire the whole structure. Several tests had to be conducted to identify the most effective way of data acquisition to avoid shadowing effects.

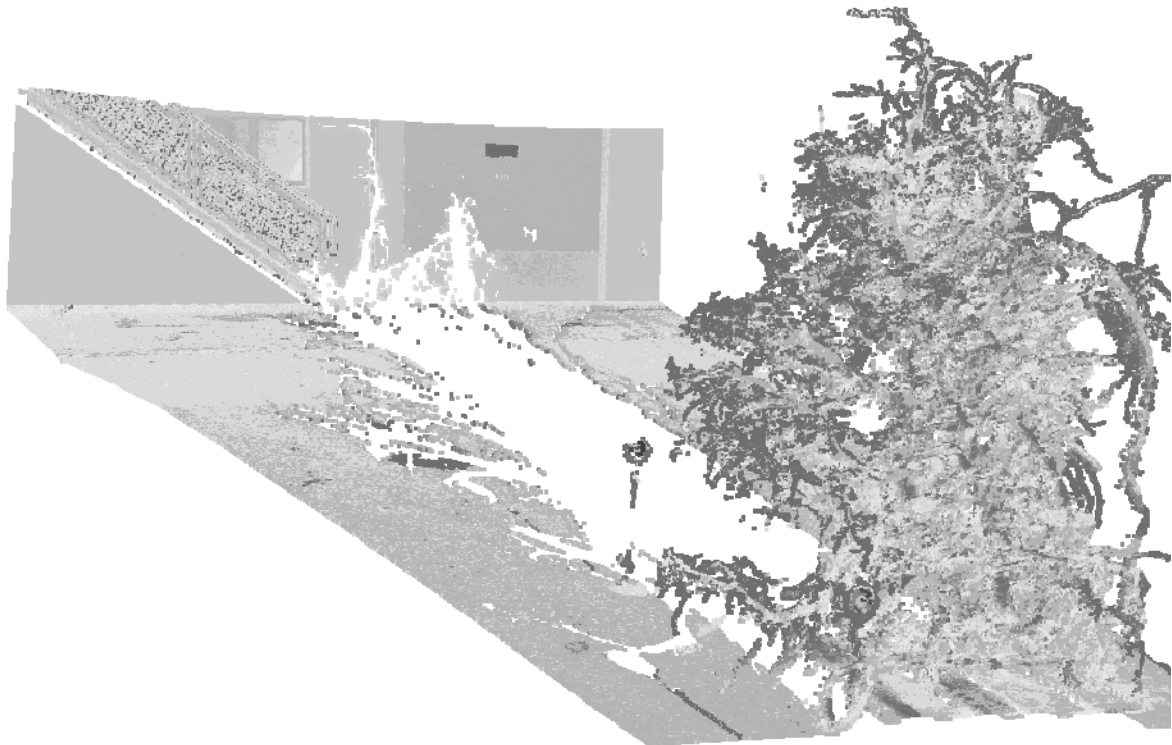


Figure 2: Perspective view of the scatter-plot resulting from one scan. White areas within the scan range represent the shadowing effects caused by the laser device and masking of roots resulting in no data.

The root was scanned from 4 directions to minimize the shadowing effects. To ensure correct orientation of each single scan, four stages with fixed points were placed around the root system. These four poles guaranteed the accurate positioning of each scan image while creating the three-dimensional model by combining the single scenes. At least two of the poles needed to be visible in each scan to enable a referenced combination of the scenes. Point-to-point measurement spacing was set to 2 mm to simplify data processing and to accelerate the procedure of the single scans for this preliminary study. With this set up, each single scan took 15 minutes. In total, it took about 1 hour for scanning and approximately 30 minutes for moving the scanner 4 times to acquire all data needed to finally represent the whole root system in the final scatter plot. The scanner detects all surfaces within its 40°x40° field-of-view. Thus, each resulting scene includes unnecessary data point areas. The first step in data processing was to extract the area representing the root system and the poles from the whole scatter plot of the area. To do this, non-target areas had to be cut out of the scenes.

Preliminary results

The resulting scenes of the root were combined to a three-dimensional scatter-plot of the entire root system (Fig. 3a). This scatter-plot consists of approximately 3 million xyz-coordinates representing the surface of the roots. A more detailed view of the individual roots of the scatter plot (Fig. 3b) illustrates a good data acquisition of roots as small as 4-5 mm, which are all well represented in the plot (black arrow in Fig. 3b). However, there are numerous scattered dots in some areas in vicinity of the coarse roots.

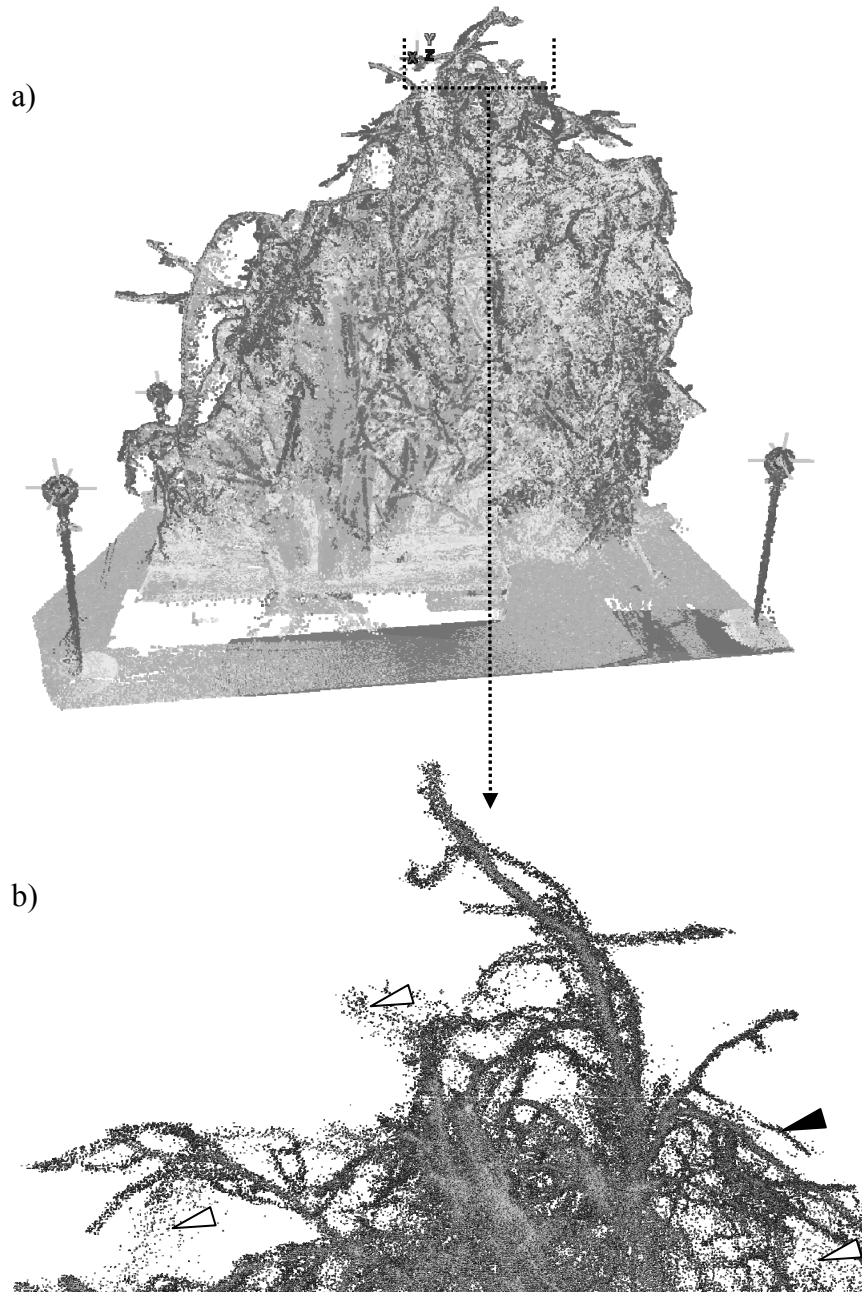


Figure 3: a) 3D-scatter plot of the root system consisting of 4 single images of the laser scanner. b) magnified view of the top section of the root system. Black arrow: Example for a root of 4-5mm in diameter; White arrows: cloud of reflected data points from fine roots smaller than 2 mm, not sufficient to represent the single roots entirely and therefore resulting in scattered areas in the scan view.

These dots are individual reflections of fine roots smaller than 2 mm, which were only partly scanned in the single scenes. The scattered areas (white arrows in Fig. 3b) are results of combining scenes with incomplete images of the respective fine roots. Nevertheless, the coarse root structure is clearly visible and single roots bigger than 5 mm in diameter can be differentiated. Consequently, the main aim of the pilot study to represent the three-dimensional structure of a complex root system in a computer has been achieved. This dataset can now be used to further analyse the root structure by creating the surfaces of the single roots and hence create a closed, three-dimensional model of the whole root system. To derive more detailed information on the structure of the root system without modelling the surfaces in detail, horizontal layers (thickness: 10 cm) were cut from the plot to generate volumetric bodies of the structure at different levels (Fig. 4).

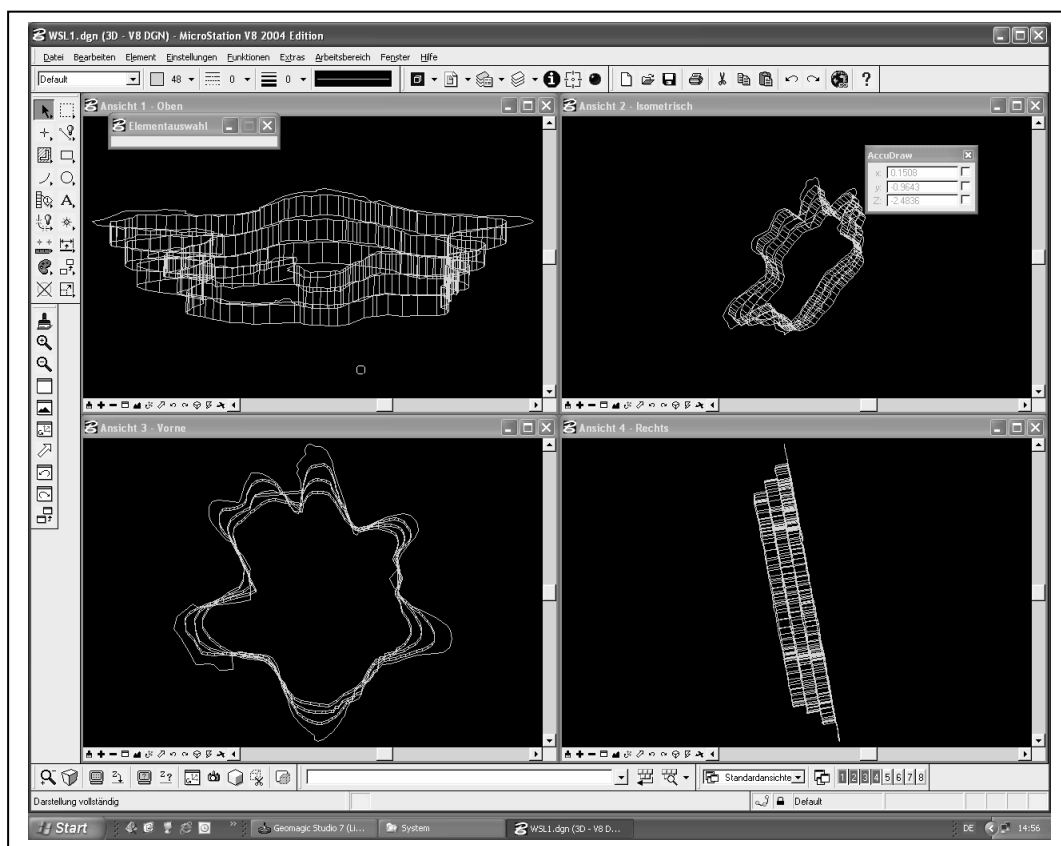


Figure 4: Illustration of composed 3D-slices of the root system (screenshot: visualized data output, CAD/CAE-Software "Bentley MicroStation"). The single volumetric bodies were created by using the section plane area and the height of the section.

The scan data of the lowermost data points girdling the surface texture of the root layer were then combined to closed contour lines. Finally the bodies were created by adding the height information of the layers using the CAD/CAE-software Bentley MicroStation. This procedure was conducted to evaluate the possibilities for a time and cost effective modelling of a three-dimensional body to e.g., estimate the biomass of a root system. This rather basic modelling worked well, but with an increasing complexity of the structure, manual data corrections became more important to accurately represent smaller roots within the structure.

Conclusions and perspectives

The of basic modelling procedure we presented here is effective and leads to more detailed information than can be achieved with other methods of root structure acquisition mentioned before. But with regard to the high resolution data of the scatter plot a more detailed modelling technique is required to fully use the potentials of the scanner data. The overall aim to analyse root system development in detail or mechanical properties of the system as a whole requires a more complex modelling and presentation of the surface of each single root within the system. This is required e.g., to enable the addition of ring-width data to the model.

Without anticipating forthcoming modelling techniques, it is obvious that data sampling for the tree(root)-ring analysis can start immediately after the scanning procedure. All samples taken from the root system will be tagged in the scatter-plot and then transferred to the 3D-model. Combining ring-width data with a 3D-model is the base for detailed future spatiotemporal analyses of the development of a mature root system. First steps towards this analysis procedure have recently been started at the Swiss Federal Research Institute WSL. The identical procedure can also be used to analyze the dimensions of stem and branches of trees. The detailed presentation of whole-tree dimensions using a 3D-Laserscanner in combination with dendrochronology in roots, stem and branches opens new perspectives in the analysis of biomass-distribution and tree-stability research.

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