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A LOW-COST TOOL-CHAIN FOR RECONSTRUCTION OF STANDING TREES OF SELECTED EUROPEAN HARDWOOD SPECIES

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ABSTRACT

The use of endemic hardwood species in forest conversion and forestation of marginal land is part of the current policy in Flanders, yet little is known about their quality. An inexpensive tool-chain is presented here for total tree assessment, starting with the reconstruction of the stem of the standing tree which can be used for calculation of taper, sweep, etc. Subsequently serial sectioning of the tree, image acquisition and registration is performed. Image processing of the discs and positioning in the reconstructed stem enables quantification of bark, veneer quality, etc. on virtual sawn or peeled logs. In combination with measured crown parameters such datasets can be used in physiological growth, yield and quality models and their predictions of wood characteristics. This easy-to-implement tool-chain generates important output for a number of forestry-wood chain related domains for lesser known hardwood species with highly irregular stem form.

KEYWORDS: Irregular stem form, forestry-wood chain, photogrammetry, three-dimensional, reconstruction, wood processing.

INTRODUCTION

A rapidly increasing demand for timber forces the industry to tap into new sources of wood material. A shift towards neglected wood species fits within this quest for alternatives. This boils down to the use of species that are considered having an inferior quality in combination with an increased use of engineered wood products which have been developed aiming at uniform strength and behaviour, levelling out inherent biological variability. The use of wood species of lesser quality also fits within the framework of sustainable forest management and especially opens up the perspective of using a country's own standing stock in a durable way to increase its self-supplying potential. In Flanders there is ample challenge for basic resource utilization. Current forest policy steers towards the conversion of secondary softwood forests to mixed forests with a majority of hardwood species naturally occurring. Furthermore, the competition in land uses in a densely populated region such as Flanders necessitates the forestation of marginal land, e.g. sandy and moist soils. It is of importance to assess the potential and optimal use of such lesser used wood species within the forestry-wood chain, moreover since there is a growing interest for the use of wood as biofuel / bioenergy (Grayson 2011). Both characteristics of the standing tree as well as the internal characteristics are necessary for a complete view on the tree's quality. Pre-harvest inventorying is the first step in the assessment of the standing stock which is necessary to prioritize and defend durable management decisions and to increase our knowledge on forest operations (Clark 2001). Furthermore, assessment of the standing tree allows selection of valuable specimens and estimation of the potential volume yield in order to create a more efficient forestry supply chain (Hapca et al. 2008). Stem characteristics are the first important evaluation parameter, with stem form as one of the prime criteria for selection of stems for the wood industry and appropriate bucking, sorting and grading. Especially trees with very demanding and irregular stem form are challenging. Several techniques are available in 2D or 3D. One of the more advanced methods is the use of terrestrial LiDAR scanners or high accuracy laser radar systems for metrology of large objects, mainly used for whole tree architecture reconstruction, including the crown (Thies et al. 2004; Xu et al. 2007; Côté et al. 2009; Rutzinger et al. 2011). For crown reconstruction the tool-chain presented here will be limited to measuring the main axes of the crown and fitting quadratic elliptic paraboloids to the data. This is far simpler than the huge variety of methods available in literature (e.g., Sinoquet and Rivet 1997; Kato et al. 2009), but fits within the search for a straightforward method based on a simple dataset. For stem reconstruction, the well-known methodology of photogrammetry is applied, which is an easy and rather cheap alternative for laser scanning but requires more user interaction and is not able to map the surface of the tree as 3D scanners do. It is often used for image-based tree modelling aiming at the creation of moderate realistic tree models from actual trees including leaves and small branches (Reche et al. 2004; Neubert et al. 2007; Teng et al. 2007; Teng and Chen 2009). Its use (Dean 2003; Hapca et al. 2007, 2008) shows the value of this straightforward technique for forest mapping and management, especially in search for a rather inexpensive and flexible technique, employable under different circumstances, both in temperate as well as in tropical environments. Mapping the internal characteristics of a tree is also crucial to assess its value. It is plausible to use non-destructive techniques such as acoustic tomography (Bucur 2005), mobile X-ray equipment or one dimensional profiles using stress waves (Wang et al. 2001), but mapping the internal features of a whole stem is difficult and these techniques are expensive and have limited resolution. Therefore destructive evaluation, at least by felling the tree, urges itself for detailed analysis (e.g. Constant et al. 2003; Pinto et al. 2006). Non-destructive techniques using X-rays (e.g. Nordmark and Oja 2004; Skog and Oja, 2009; Wei et al. 2011) are very suitable for this purpose as well but necessitate rather substantial equipment and complex processing. Serial sectioning of the stem and photographing is considered a cheap alternative.

In this paper a low-cost tool-chain is presented for standing tree assessment, based on a combination of a modified version of the procedure of Hapca et al. (2007) and a modified protocol of Pinto et al. (2006), enabling data retrieval on the shape of the tree and the internal structure . In addition, a simple procedure for measuring crown parameters is shown as well, allowing to build a simple model of the crown. Such a general inexpensive framework of image-based tree processing for physiological growth, yield and quality modelling and wood technological purpose is elaborated for a selection of birch and willow trees, with very demanding stem form and internal characteristics.

MATERIAL AND METHODS

Tree species

The endemic wood species under this study are birch (*Betula* spp.) and willow (*Salix* spp.). Birch has a good growth on low fertile soils (Dieguez – Aranda et al. 2006), as well as there are a considerable number of willow species growing well on marginal land. Three birch and three willow trees were used to illustrate the tool-chain. The birch trees originate from Weelde, located in the northern part of the province Antwerp, Belgium. The willow trees originate from Semmerzake, in the central part of the province East Flanders, Belgium. The willows were felled, sectioned and their internal structure was reconstructed, while for birch the reconstruction was limited to data derived from the standing tree and crown.

Measurements and image acquisition of the stem

All pictures for photogrammetry were taken with a Sony Cybershot 8.0 Megapixel, mounted on a tripod, and positioned in the plane of a laser focused at breast height of the tree. The camera is tilted at an arbitrary angle to visualize the tree at a moderate distance with maximal usage of the field of view. The angle of the camera to the horizontal plane is measured with a laser level with a resolution of 0.1°. All distance measurements, such as the camera to tree distance, were measured with a measuring rope with a resolution of approximately 0.5 cm. Additionally, the angle of the first picture with the northern direction is measured with a compass with a resolution of 1°.

Crown data

For the birch trees, the following crown data were measured with a Vertex III hypsometer with a height resolution of 0.1 m and measuring rope (Fig. 1): branch-free height (h), height of maximum crown diameter ($h+h_2$), maximum height ($h+h_1+h_2$), maximum diameter ($r_{M1}+r_{M2}$) at h and orientation of maximum diameter to the north and diameter perpendicular to that direction ($r_{m1}+r_{m2}$).

Serial sectioning and image acquisition of discs

Once the willow trees were photographed, they were felled, bucked and transported to the laboratory. The logs were sawn up to discs of approximately 5-10 cm thickness and were oriented north-south, according to the markings on the logs. The discs were illuminated uniformly and photographed. Details on the image processing of the discs are given in the results section.

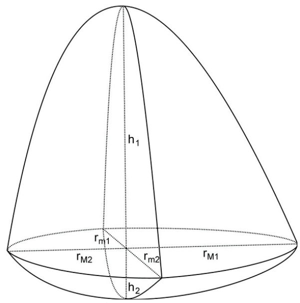


Fig. 1: Crown dimensions.

RESULTS

Low-cost tool-chain

All calculations and visualization are performed in the MATLAB® environment.

Image acquisition, calibration and rectification

The first step in total stem reconstruction is the acquisition of two or more images of the standing tree (Fig. 2A).

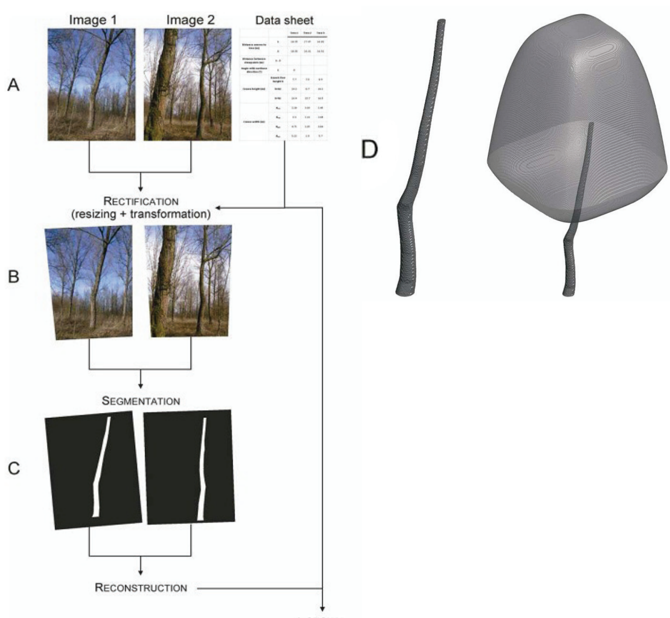


Fig. 2: Reconstruction of the standing tree: A) digital images taken from different positions; B) rectified images; C) tree segmentation; D) tree reconstruction with an example of crown rendering.

Both distance from camera to the tree and the camera angle to the horizontal plane and northern direction are recorded. A calibrated stick is placed next to the trunk and a picture is taken. The calibrated stick is used to determine the size of an image pixel and calibrate the image. As an alternative, the diameter at breast height can be taken as reference for calibration instead of the calibrated stick when image rotation is negligible and the diameter is sufficiently wide for a correct assessment of pixel size. The same procedure is repeated for at least one or two extra directions, depending on the accessibility of the terrain and visibility of the tree. The in-between distance of each position is measured also. In order to correct for lens distortions and tilt of the camera, off-line calibration is necessary (Fig. 2B). Therefore a grid with fixed distance between the nodes is photographed at same tilt angle of the camera with the horizontal plane at which images of the tree were taken, to derive the piecewise transformation field. Such transformation corrects for unequal distances between the nodes of the grid and as such not only corrects for tilt but image distortion and local scale differences are countered as well. Shear is not accounted for as it is assumed negligible. This transformation is then applied on the acquired images. Furthermore, the images from different viewpoints are not taken at similar distances and need to be corrected too. The distance from camera to tree is used to resize the image(s) according to the first image, which is used as base.

Tree segmentation, profile extraction and crown reconstruction

After resizing and transformation, the tree in the multiple viewpoint images is segmented (Fig. 2C). During semi-automatic processing the grow-cut (Vezhnevets and Konouchine 2005) or active contour algorithm (Chan and Vese 2001) can assist in segmentation but in most cases manual demarcation of the tree boundary is faster and necessary due to interfering structures such as small branches, high grass, other trees, etc. Based on the ribbon on breast height, images are shifted likewise at equal height. It is assumed that the centre of the tree in all images coincides. Therefore the centre of the tree in one image can be linked to the centre in another image at each height. Basic trigonometry incorporates the angles at which the images are taken using the distances between all positions and their distance to the tree. This eventually results in an array of x, y and z coordinates representing the centre of the tree and for each image two additional matrices with the x, y and z data points of the tree boundaries. As the tree centreline always deviates from a perfect straight line, the diameters measured based on the calibrated stick might deviate from the real diameters due to out-of-plane positioning. An approximate correction makes use of the position of the traced centre at every height and the diameter at breast height as reference diameter. The difference in camera – tree distance between a certain height and breast height is used as a correction factor. Normally the effect will be minor because the camera is located rather far from the tree but the influence of trees with strong leaning could be substantial. Depending on the amount of images, the cross-section of the tree at every height can be visualized by fitting a circle, a single ellipse (cf. the work of Saint-Andre and Leban (2000) on Norway spruce) or a closed spline to the boundary points for visualization purposes of the stem. Finally, the stem can be reconstructed as well as the crown (Fig. 2D). The latter reconstruction consists of eight quadratic elliptic paraboloids fitted to the measured data.

Serial sectioning and processing

The felled trees are sawn into discs and photographed. The image stack is then available for further processing (Fig. 3A). First, fine alignment to the north-south direction by image rotation is accomplished. Second, the disc is separated from its background (Fig. 3B). Third, semi-automatic demarcation of different features, in this case bark and heartwood, using a magic wand function and appropriate correction, is done on the disc image (Fig. 3C).

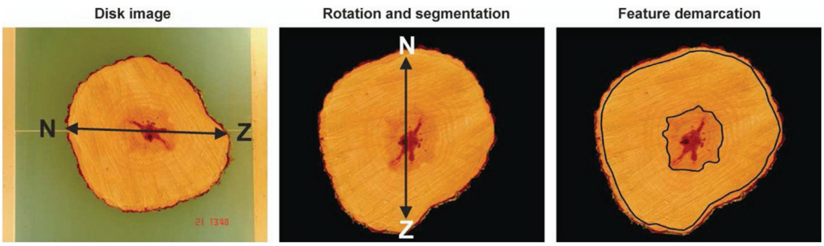
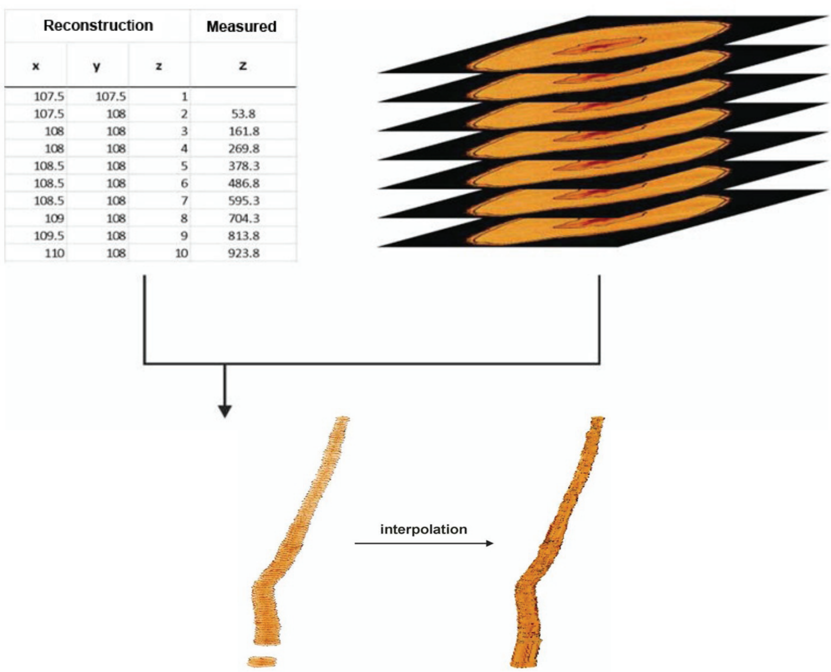


Fig. 3: Processing of disc images: A) original disc image; B) rotated and segmented disc; C) demarcation of bark and heartwood.

The pith is marked manually. In fact, every feature of interest visible on the discs, such as knots, disease spots, etc, can be classified, manually or (semi-) automatically and stored in a matrix.

Total tree reconstruction

Finally, the reconstructed tree profile and the image stack of processed disc images are combined. The centre of the bounding box of the discs equals the centre of the reconstructed tree. The amount of discs depends on the sampling frequency.



Reconstruction			Measured
x	y	z	z
107.5	107.5	1	
107.5	108	2	53.8
108	108	3	161.8
108	108	4	269.8
108.5	108	5	378.3
108.5	108	6	486.8
108.5	108	7	595.3
109	108	8	704.3
109.5	108	9	813.8
110	108	10	923.8

Fig. 4: Positioning of the processed disc images in the tree and interpolation of discs.

As such the true shape of the tree can be approximated by creating a surface from the outer boundaries of the segmented discs. Missing discs or discs at uneven spaced distance can be interpolated. Disc shape can be interpolated by simple distance weighted interpolation while the R, G and B channels of the colour images of the discs are interpolated using non-rigid b-spline grid image registration (similar to Klein et al. 2011). As a result the internal volume of the tree is reconstructed and the outer shape is obtained as well (Fig. 4).

Virtual wood processing

The digital reconstruction of the tree stem allows further analysis. Boards can be sawn from the logs, with or without demarcation of heartwood, bark, etc. Further analysis of the logs comprises virtual peeling, a concept described by Bhandarkar and co-authors (2002) on CT scans of logs. Peeling requires a log with a cylindrical shape, a minimum core diameter and a minimum length. Logs have a shape that differs from the perfect cylinder and have a certain sweep or slope (Fig. 5A). The optimization problem of finding the maximum inscribed cylinder is simplified by assuming that the axis of the cylinder is equal or parallel to the reconstructed axis of the log. The maximum cylindrical volume can be found by multiplication of the binary cross-sectional planes of the log perpendicular to the angle of slope (Fig. 5B) taking into account the minimum length of the required cylinder. The diameter of the maximum inscribed circle (Fig. 5C) of the product of cross-sections is found by distance transformation.

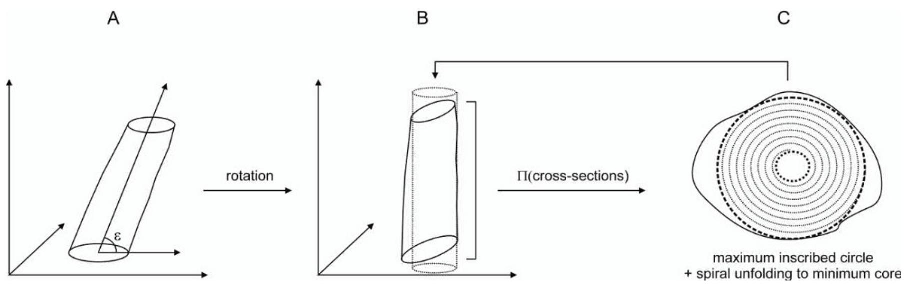


Fig. 5: Protocol of cylinder fitting: A) sloped log; B) rotated log with cylinder fitting; C) top view on log and fitted cylinder with Archimedean spiral.

If the required length is not reached, the length of the log is increased with a small step while the maximal diameter decreases. As such the stem is split up in different parts for peeling. Once the inscribed cylinder is extracted from the volume, solving the roll equation of an Archimedean spiral results in the length of the veneer sheet with certain thickness and minimum core diameter:

$$r = A\theta \tag{1}$$

where: θ - the angle in radians swept out as the spiral increases from 0 to the radius of the cylinder. Each wind will increase *r* with a certain thickness *t* and θ will increase with 2 radians:

$$A = \frac{t}{2\pi} \tag{2}$$

The length *L* for a cylinder with minimum core diameter din and outer diameter dout equals:

$$L(d_{in}, d_{out}) = L_{out} - L_{in} \tag{3}$$

or

$$L = \frac{t}{4\pi}\left[\theta\sqrt{1+\theta^2} + \ln\left(\sqrt{1+\theta^2} + \theta\right)\right]_0^{\theta} \tag{4}$$

Virtual peeling of the cylinder with visualization of the resulting veneer sheet is based on the same equation, but thickness depends on the resolution of the disc images. The cylinder is spirally unfolded and the voxel values are stored in a matrix, resulting in a virtual veneer sheet, with or without feature demarcation.

Results for example species birch and willow

The following results illustrate the possible output of the tool-chain for a set of birch and willow trees. The measured data for the birch and willow trees necessary for reconstruction are given in Tab. 1.

Tab. 1: Input data of birch and willow trees.

	Distance camera - tree (m)			Angle with northern direction (°)			Crown heigth (m)			Crown width (m)			
	image number			image number									
	1	2	3	1	2	3	h	h + h_2	h + h_1 + h_2	r_{m1}	r_{m2}	r_{M1}	r_{M2}
Willow	14.3	13.7		90	170								
	15.0	15.2		120	170								
	18.2	20.2		90	160								
Birch	15.1	15.3	14.9	270	30	150	8.5	15.0	23.3	3.7	2.1	3.8	2.5
	11.8	13.2	12.0	220	350	100	8.5	11.5	21.1	2.6	2.5	3.9	2.6
	13.7	13.1	13.1	120	240	20	9.0	11.4	19.4	2.4	2.0	2.9	2.3

The reconstructed stems with fitted cylinders for peeling and crown volumes for the birch trees are displayed in Fig. 6.

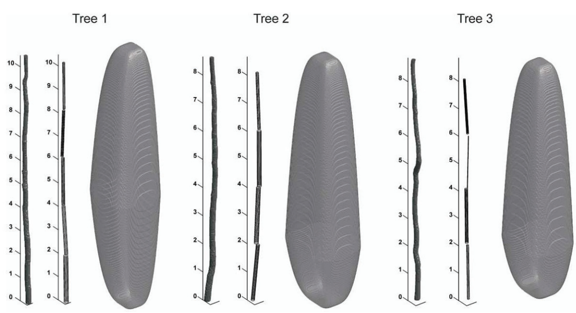


Fig. 6: Reconstructed birch trees with fitted cylinders and crown isosurface (axes in meter).

The reconstructed stems are irregular and the centreline deviates considerably from a straight line. For tree 1, five cylinders were fitted to the stem while only four cylinders were fitted for the two other trees. Although their general crown shape is similar, tree 1 has more calculated crown volume in the lower part than the other two.

Three willow trees are reconstructed as well using the digitized cross-sections with demarcation of heartwood and bark. Other important features such as ring width, knots, etc are not measured as the purpose of this paper is to illustrate the tool-chain, not specific results for these particular trees. When mapped however, it is easy to integrate these features in the tool-chain. Fig. 7 illustrates the cross-sectional analysis of the debarked willow trees.

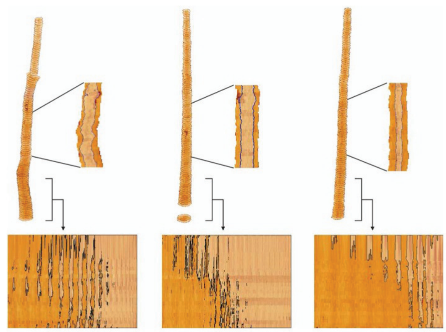


Fig. 7: Reconstructed willow trees with example of demarcated heartwood on a board sawn through the centre and a veneer sheet.

A radial section through the middle part of the tree with heartwood boundaries illustrates the result of reconstruction and interpolation by combination of 2D pictures of the standing tree and positioning of the cross-sections in the tree volume.

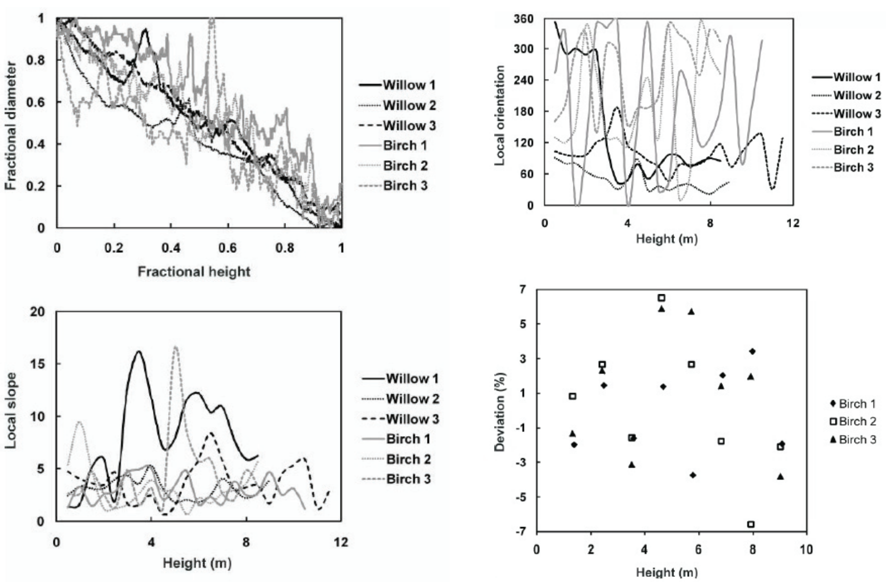


Fig. 8: Calculation of fractional diameter in function of fractional height, local slope and local orientation in function of height and the deviation between the measured diameter and the calculated diameter based on the reconstructed tree stem as a percentage of the measured diameter for the birch and willow trees.

The bottom part of the figure shows veneer sheets obtained by peeling a log of two metres with indication of the heartwood. Logically, the size and position of the heartwood as well as the shape of the tree has an influence on the distribution of heartwood on the virtual veneer sheets. Taper, local slope and local orientation were calculated for the six trees and are plotted in Fig. 8. Also given in Fig. 8, is the difference between measured and calculated diameter for the first 9 meters of each birch stem.

The maximum difference is approximately 7 % of the measured diameter. Taking into account the distance at which the stems are photographed, the rather small diameter of the stem, the possible errors on stem demarcation and camera tilt, the irregular stem shape (small irregularities at the bark, non-circular shape) and the downsampling of the volume for total stem reconstruction, this is rather good. Furthermore, most errors are within the 3-4 % of the actual diameter. Fig. 9 illustrates the direction dependent growth and lean of the six trees, with a distance of 10 cm between each circle.

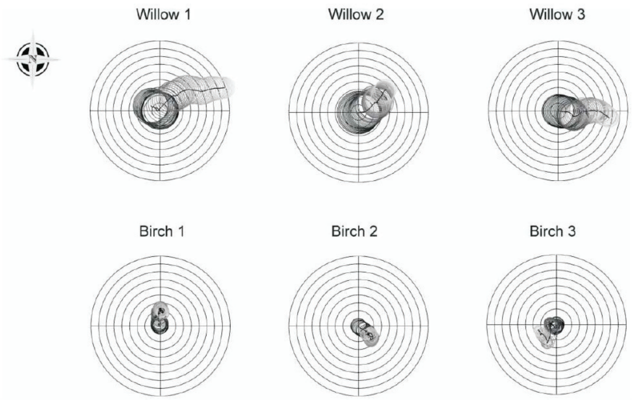


Fig. 9: Direction dependent growth and lean of the six trees.

The slope of willow and birch trees is relatively high, locally, due to a strong leaning. The birch trees also exhibit a strong curling effect which is not present in the willow trees, yet the willows lean much more than birch trees do. Other data such as volume of the tree based on the pictures only or on reconstructed disc volume and veneer length is listed in Tab. 2.

Tab. 2: Volume data and veneer length based on the reconstructed profile from the pictures (tree) or with incorporation of the disc contours (discs).

	Height (m)	Volume (m^3)				Veneer length (m)	
		Tree	Measured	Heart	Bark	Tree	Discs
Willow	8.78	1.00	0.96	0.21	0.13	281	154
	9.27	1.08	0.97	0.27	0.13	377	257
	11.22	1.09	0.97	0.13	0.15	359	204
Birch	10.51	0.24				55	
	8.93	0.19				40	
	8.89	0.16				13	

Birch 3 has only limited veneer length due to its rugged form and tapering and apparently this is also related to a low crown volume.

DISCUSSION

The proposed method starts with the extraction of the profile of the standing tree by using two or more rectified images taken from different angles. Obviously careful control of the camera position is crucial for a correct reconstruction of the tree by transformation and rotation of the images. Especially camera tilt has to be controlled and measured accurately in order to avoid significant height and diameter deviations. The use of self calibration of the camera as described in Teng et al. (2007) is only part of the solution as it is still necessary to control the set-up. Furthermore, reconstruction from images with narrow viewing range is only sufficient when assuming a cylindrical cross-section of the tree stem. For the willow trees the cylindrical assumption is a simplification neglecting the real cross-sectional form. When a larger viewing range is possible, a circle, a single ellipse or a closed spline is fitted to the boundary points. Whether or not a single ellipse model is sufficient should be studied further, such as is done by Saint-Andre and Leban (2000) for Norway spruce. Due to difficulties associated with picturing trees in their natural environment, especially in the forest, flexibility concerning distance to tree and viewing angle is necessary which can be accomplished with the proposed method. A drawback of the method is that concave structures can't be visualized as inward curving surfaces are not resolvable on projections. For trees with significant deviation from the basic ellipse shape, terrestrial laser data could do a better job. Another option is the use of a portable scanner (Tong and Zhang 2008) which results in data limited by the height of the standing tree. Additionally, correct delineation of the tree on the images is also critical for an optimal reconstruction of the shape and estimation of diameters and volumes. The time to take at least two pictures taking into account all measurements for accurate determination of camera position and orientation is at least 30 minutes. For scientific purposes this is reasonable considering the time it takes to measure the other tree characteristics and especially when investigating the total tree by cross-sectional analysis. For total stand characterization it might be cumbersome to use photogrammetry, although more than one tree can be viewed and subsequently analysed in a single picture. Again, the main bottleneck is the demarcation of the tree as it is very difficult to automate this process due to a nonstandardized background. Once the general stem shape is reconstructed, straightforward analysis allows immediate characterization of taper, local slope and local orientation. These param eters are important indicators for log bucking. Volume estimates are also an outcome of this analysis and could be used in addition to taper models (Ozcelik 2008; Lejeune et al. 2009). Further processing of the data would lead to a three dimensional model for geometric log description as explained in Rönnqvist et al. (2000). Due to the relative inexpensive and flexible set-up, the described method could also be exploited in tropical forests where the access to high tech equipment is restricted and even less appropriate. In addition to the reconstruction of the stem, crown shape parameters can be used to visualize the crown and calculate the volume as such obtaining data important for avian habitat analysis, forest fire simulation and other research areas within forestry. Although only one model was used consisting of eight quadratic elliptic paraboloids, several other mathematical crown shapes can also be implemented. For free standing trees one can of course rely on the pictures taken (Phattaralerphong and Sinoquet 2005). For a very precise mapping of the crown, implicit surface reconstruction of airborne lidar data, which is a widely applicable individual treespecific approach, is recommended (Kato et al. 2009) instead of the explicit reconstruction using mathematical models. With a combination of crown shape and tree stem a virtual forest can be generated. This can be used as validation set in the study of the effect of environmental variables on tree characteristics in physiological growth and yield models (process-based) such as RetroSTEM (Kantola et al. 2008) or ANAFORE (Deckmyn et al. 2008) and dendrometrical studies in general. But for full potential studies, the internal characteristics should be mapped as well. The method described in this paper, with consecutive digitalization of sawn disc surfaces, is a labour-intensive one, certainly when knots, heartwood, bark, and other features have to be demarcated manually. The interpolation of missing discs or uneven spaced discs is now done using non-rigid and distance-based techniques, yet using a within tree model of variation of properties would allow to decrease the sampling frequencies and as such speed up the process considerably. Intelligent classification for multivariate image analysis of near infrared imaging using support vector machines can be part of the solution (Liu et al. 2005). Image analysis, such a described in Giroud et al. (2008) studying the red heart in paper birch, can be further worked on. A more elaborate and similar approach was followed by Wernsdörfer et al. (2005) for the detailed analysis of red heartwood in beech using a log scanner and image analysis software for the processing of the discs. Also X-ray analysis of the discs or even whole logs without disc slicing is another possible approach (e.g., Schmoldt et al. 2000; Bhandarkar et al. 2006), in combination with virtual peeling of the scanned logs (Schmoldt et al. 1996). Yet the colour information available from this method and the coupled virtual sawing and peeling allow visualization of the internal structure in the visible wavelength domain, which is also important for assessment of quality considering its use for aesthetical purposes. Again, as a low-cost tool was searched for, standard digital photography seemed most suitable. Another possible protocol is peeling of logs and continuous inline photographing of the veneer surface to reconstruct the tree volume.

Especially for the study of knots, this would be an advantageous alternative, but requiring more technical expertise. In any case, the availability of the true shape of the stem also allows to model ring eccentricity and pith position according to the method described in Saint-Andre and Leban (2001). Also, reconstructed trees and segmented features can be used as input in sawing simulators for bucking and optimal sawing (Todoroki and Rönnqvist 2002; Pinto et al. 2003) and test out the process-based models (Kantola et al. 2007; Deckmyn et al. 2008).

CONCLUSIONS

The tool-chain presented here, consisting of stem reconstruction based on photogrammetry, crown modelling and disc analysis of the sawn tree is a rather inexpensive method for research along the forest-wood chain, starting from the standing tree and resulting in virtual sawing and peeling. The required tools are a tripod, camera, (laser) level, measuring rope, compass and a computer with appropriate software. In combination with a low-cost field mapper (range finder, GPS, rugged computer) this tool-chain would give a very powerful measurement station. Due to the flexibility, it could also be used in the tropics and calculations could be performed elsewhere if necessary. Rigorous calibration of the camera is an absolute necessity and could be replaced by radar scanning systems or laser scanners if available. Sectioning and digitalizing is time and labour-intensive, but the information derived from the analyses is diverse and can be used as input or as a validation set for growth modelling. Furthermore, with optimization of the segmentation algorithms, semi-automatic processing might be possible. Also the incorporation of X-ray images and NIR images of the discs could add substantially to the knowledge of chemical and structural properties of the tree. Peeling and subsequent reconstruction could be an alternative to cross-sectional analysis. Valuable information can also be obtained by reconstructing the tree branches using a similar approach as elaborated for the stem, taking into account possible self-obscuring. In total, this easy-to-use and inexpensive framework can generate valuable output for several domains within forestry and wood research for quality assessment focusing on lesser used tree species with very irregular stem shape. As data of disc features as well as data of different imaging modalities can be added, the framework is rather easy expandable as well.

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