Knots in CT scans of Scots pine logs

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Abstract

Outer dimensions of logs can be detected by modern optical scanners to a high precision. Quality parameters describing the outer shape as taper and curvature can be calculated from this data, based on algorithms agreed between the trade partners. The detection of inner log features is not used in the industry to a standardised and wide spread so far. However inner log features can affect the products sawn from a log. Knots, for example, can limit the utilisation for construction purpose or optical usage.

In this study computed tomography (CT) was used to detect the three-dimensional shape of knots in Scots pine logs grown in the southern part of Sweden. In the CT images different densities are represented by different grey-values. Regions with the same or similar density will show the same grey-value and thus can not be distinguished in these images. The absorption characteristics of wood lead to a contrast between knot material and regular stem wood in the heartwood part of the log, but to very low contrast in the sapwood. As the sapwood's high water content absorbs radiation in similar way as branch wood the knots and the surrounding material have a similar density and therefore a similar grey-value. Thus knot detection in sapwood by CT methodology is restricted.

For this investigation the main focus was set on the automatic detection of the three-dimensional shape of the knots in the heartwood applying image analysis methodology. In a first step an algorithm was developed to eliminate the sapwood area in the CT images. It uses a polar transform with the pith as pole for each slice, followed by a detection of the heartwood-sapwood-boundary on the radial coordinate. The obtained values are afterwards corrected by interpolation, to bypass the whorls, and smoothing in longitudinal direction of the log. In the main step threshold values and morphological procedures were applied to detect the knots – resulting in a 3D representation of the log with the shape (including position, orientation and size) of all knots in the heartwood.

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1 Introduction

Outer dimensions of logs can be detected by modern optical scanners to a high precision. Quality parameters describing the outer shape as taper and curvature can be calculated from this data, based on algorithms agreed between the trade partners. The detection of inner log features is not used in the industry to a standardised and wide spread so far. However inner log features can affect the products sawn from a log. Knots, for example, can limit the utilisation for construction purpose or optical usage severely.

In this study computed tomography (CT) was used to detect the three-dimensional shape of knots in Scots pine (*Pinus sylvestris L.*) logs grown in the southern part of Sweden. In the CT images different densities are represented by different grey-values. Regions with the same or similar density will show the same grey-value and thus can not be distinguished in these images when directly adjacent to each other. For softwood the absorption characteristics of wood lead to a contrast between knot material and regular stem wood in the heartwood part of the log, but to very low contrast in the sapwood. As the sapwood's high water content absorbs radiation in similar way as branch wood the knots and the surrounding material have a similar density and therefore a similar grey-value. Thus knot detection in sapwood by CT methodology is restricted.

The project Woodvalue aims to develop a standardized methodology at European level to define, measure and value the efficiency and profitability of key wood supply chains - from standing trees to end consumer products. Working package 1 is concerned with the definition and quantification of the wood characteristics using different scanning and measuring systems including x-ray scanning. The research activities comprise characterisation of stem, wood and fibre properties in order to facilitate optimisation of the wood supply process from the perspective of the successive value chains and end products. This is the base for efficient classification of the wood and respective segregation of the assortments. Branches represent the most important structural feature for future utilisation of sawn timber. Thus their identification, precise location and quantification as early as possible ahead of primary conversion will improve production yield and product quality, and reduce material input and volume of downgraded products.

2 Material and methods

2.1 Material

For the project including this study in total 60 Scots pine (*Pinus sylvestris L.*) logs from 31 trees were used. They were harvested in two different stands in Sweden. For this study two logs were chosen for the reference measurements. The first log was a butt log of one tree, the other an intermediate log of another tree. For two whirls per reference log manual measurements were taken. These four whirls included 21 knots.

2.2 Methods

2.2.1 Acquisition of CT data

All logs were scanned with the Microtec CT.LOG located at the FVA in Freiburg. For the scans a voltage of 180 kV, a current of 14 mA and a number of 900 views per rotation were used. The resolution in crosscuts was 1.1 mm; for longitudinal resolution 5 mm was chosen. From raw data a three-dimensional data block is computed, where the grey-value of each voxel (3D-pixel) represents the amount of x-ray absorption and x-ray scattering of the corresponding point in the log.

2.2.2 Analysis of CT data

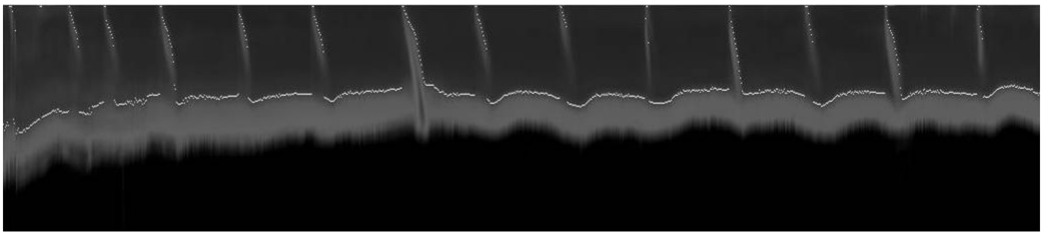
The CT data is analysed using the procedures briefly described in the following paragraphs. The result is a three-dimensional label image, where the value of each voxel is the number of the knot, it belongs to, or zero, if it does not belong to any knot. From this label image the three-dimensional shape of every single knot in the heartwood can be extracted.

2.2.2.1 Detection of the pith

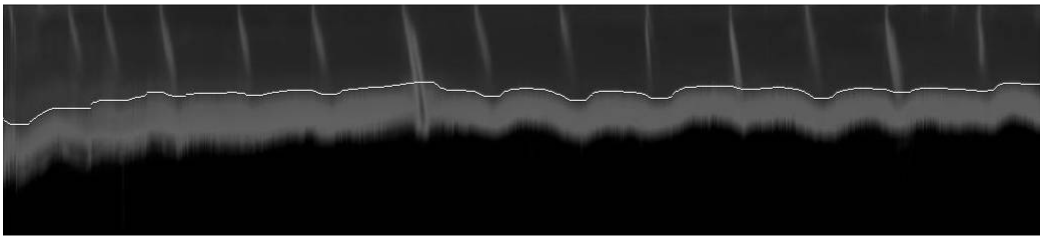
The pith is the origin of every knot and an approximation of the geometrical centre of a log except for logs showing extreme eccentricity. The position of the pith plays a decisive role in the analysis of CT data, and thus the first step of analysis was the detection of the pith. A modification of the method described by Longuetaud (Longuetaud *et al.* 2004) was used for the determination of the pith position. This method, derived in principle from the Hough transform, exploits the fact that the pith is supposed to represent the centre of a set of concentric circular structures, i.e. the annual rings, and detects the pixel representing the pith position as the point of maximum intersection of lines in gradient direction in an accumulator array.

2.2.2.2 Cropping of heartwood area

The next step in the analysis is to identify the heartwood-sapwood-boundary, as knots cannot be detected to appropriate accuracy in sapwood. The CT images were transformed into polar coordinates using the detected pith as centre. The image transformation facilitated the delineation of the sapwood-heartwood-boundary by altering circular structures around the pith to linear structures. The algorithm employed sequentially detected boundary points between heart- and sapwood in each column (representing radial lines in the original space) by comparing pixel intensity to a predefined threshold. The first pixel with intensity above the threshold was set as boundary point. Since pixels belonging to a knot region also exceed the threshold applied, this simple algorithm would lead to delineation of knots as sapwood and thus to the removal of these regions being of proper interest in the subsequent masking operation. Consequently, a correction function was implemented in the algorithm. For each of the 360 azimuths a filter in longitudinal direction was applied which localized the low amplitudes of the boundary points caused by knots. The sections containing these amplitudes were then bridged by linear interpolation and finally the boundary line was smoothed by median-filtering in the longitudinal direction.



a)



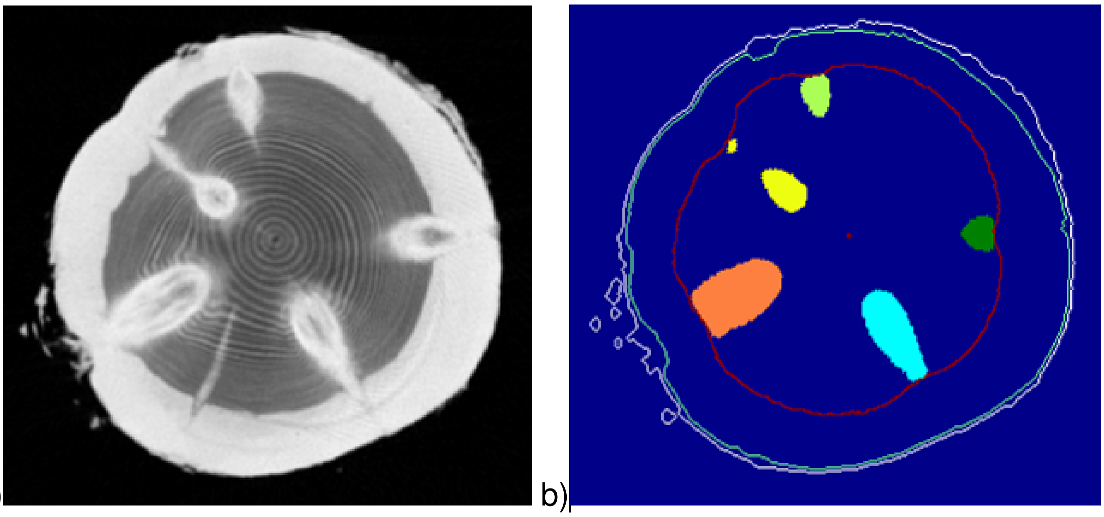
b)

Figure 1: Longitudinal cut representing one angle with boundary points; a) only using threshold, b) after bridging of knots and smoothing

After back-transformation to Cartesian coordinates these boundary pixels form a polygon with 360 corners. This polygon was used as a clipping mask for every slice resulting in a 3D data block only containing the heartwood.

2.2.2.3 Detection of the knots in the heartwood area

The knots in the heartwood were detected by applying a threshold. Morphological operations (see Serra (1982) and Serra (1988)) were used to smooth the shape of the knots and to remove unwanted small regions resulting for instance from resin pockets or other compounds in the wood with similar absorption properties regarding x-rays. The first step of post-processing was a “hole filling” operation. It changes non-knot-pixels, completely surrounded by knot-pixels, to knot-pixels. Holes inside knots can result from parts with lower density like for example the pith of the branch. The “hole filling” operation was applied on two-dimensional crosscuts. After that a morphological “open” and a morphological “close” operation were executed. The “open” operation was applied with a small structuring element (maximum radius three pixels) to remove small groups of pixels not resulting from knots. The “close” operation, aiming to smooth the shape of the detected knots, used a bigger structuring element (maximum radius five pixels). Both structuring elements used a couple of circular shaped slices to form a flattened ball. The reason for not using a sphere is the difference in resolution between crosscuts and longitudinal direction. Finally connected components were labelled, giving each knot a unique label. In Figure 2 the original CT image of one crosscut of a log is shown on the left; where one the right the labelled knots are displayed in different colours, as they are recognised by the described procedure. Additionally pith, heartwood-sapwood-boundary, outer shape and bark are marked.



a) b)

Figure 2: a) Crosscut of a CT data block of a pine log; b) Identified knots, pith, heartwood-sapwood-boundary and outer shape of the same crosscut

2.2.3 Preparation and manual measurements for calibration purpose

Before cutting the log a longitudinal line was drawn along the whole log. This line was used later on as reference for direction measurements. Additional marks for the longitudinal position were added before cutting short sections just including one whirl. These short sections were then cut into discs with a thickness of 10 mm (see Figure 3a). On every disc for every knot the minimum (r_1) and maximum (r_2) radial distance to the pith was measured (see Figure 3b).

a) b)

Figure 3: a) Discs from one whirl used for manual measurements; b) Manual measurements for one knot on one disc

Measurements of the width, perpendicular to the radius, were taken for every knot. For small knots only one width was measured; for bigger knots three to five measurement at equidistant radii were taken. Additionally the angular direction (φ) of each knot on each slice was measured using the line on the outside of the log, described earlier, as 0°. On slices where the pith of the knot was present, this was chosen for measuring the angle, on other slices the positions of minimum and maximum radius were used to estimate the angle.

3 Results

For each log the procedures, explained in 2.2.2, were executed. The derived, three-dimensional knots were compared to the manual reference measurements.

Three parameters were compared to assess the accuracy of knot detection and quantification; direction of knot by azimuth, position of inner and outer boundary of knot wood in radial direction against stem wood and the width of knots in tangential direction compared to measured knot width in disc cross sections.

In Figure 4 the direction of the knots in the CT data, which is the direction of the centroid of the identified 3D-knot, is compared to the reference measurement. For each knot the reference direction is calculated as the mean value of the direction angles, measured on all slices this specific knot appeared. For both logs the two different measurements show a high correlation. In Figure 5 the difference of both measurements is plotted, where the whirls 1a and 1b are from log 1, 2a and 2b from log 2. The deviation of the two measurements varies in the range of -6° and 6°. In all whirls positive and negative deviations can be observed.

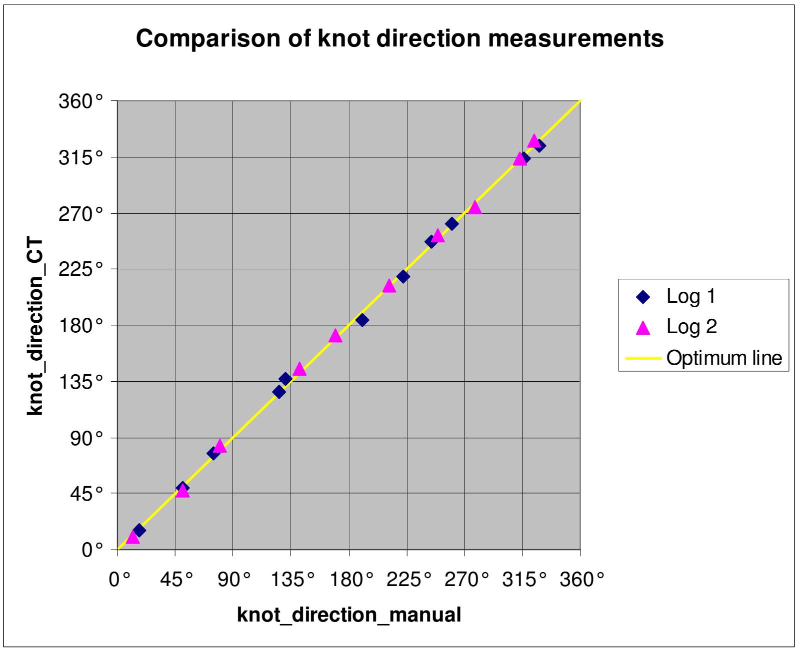


Figure 4: Manual and CT measurements of knot direction by azimuth

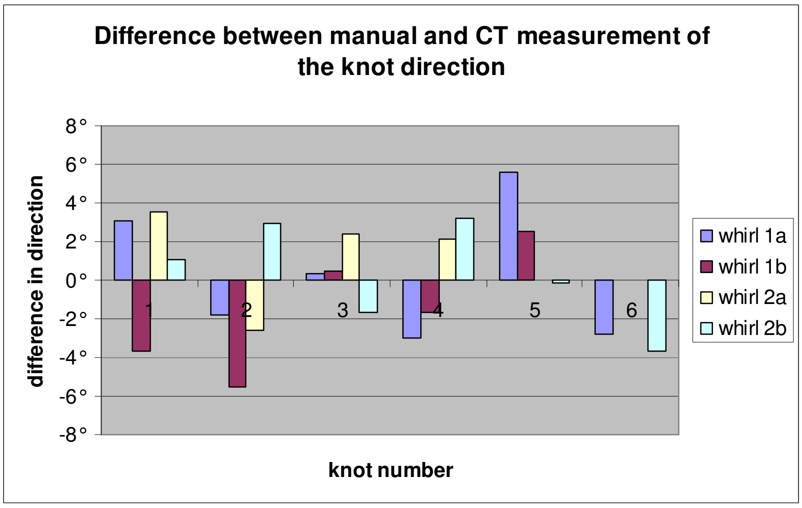


Figure 5: Difference between manual and CT measurement of the knot direction by azimuth (whirl 1b had five knots, 2a four knots)

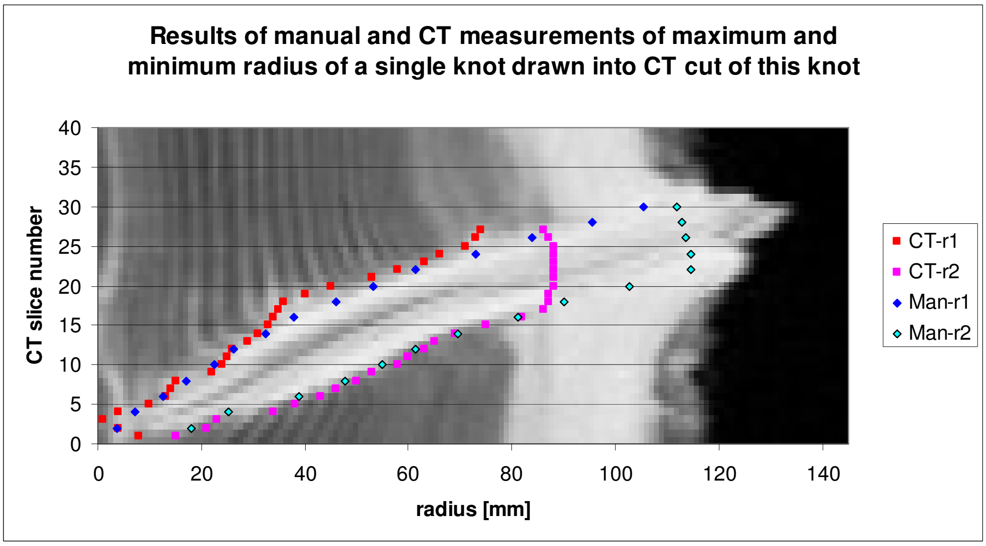


Figure 6: Results of CT (red and pink) and reference (dark and light blue) measurements of maximum (r2) and minimum (r1) radius of a single knot drawn into CT cut of this knot

Figure 6 shows the good accordance of the minimum and maximum radius of a single knot detected in all slices where this knot is present and the reference measurements on the discs. For the CT data, slice means a crosscut from the CT data block and therefore has a thickness of 5 mm. The discs used for manual measurements had a thickness of 10 mm, so manual data only exists for every second CT slice. The CT procedure so far only identifies the knots inside the heartwood, so the maximum radius of the CT measurement (CT-r2) returns the heartwood-sapwood-boundary, where the knot continues in the sapwood. The branches were removed between the CT scan taken and the manual measurement, thus the manual measurement does not completely correspond to the outer shape of the CT measurement.

In Figure 7 the maximum width of the knots in CT data is compared to the maximum of the reference measurements for each knot. In some cases the knot width shows a high deviation between the two measurements. This deviation is presented in larger detail in Figure 8; a deviation up to 10 mm overestimating and underestimating the manual measurement can be found.

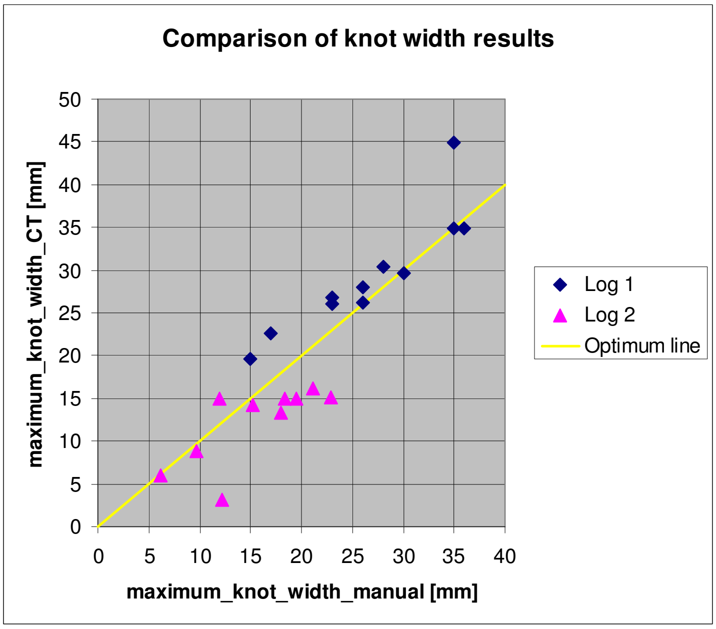


Figure 7: Results of knot width measurements

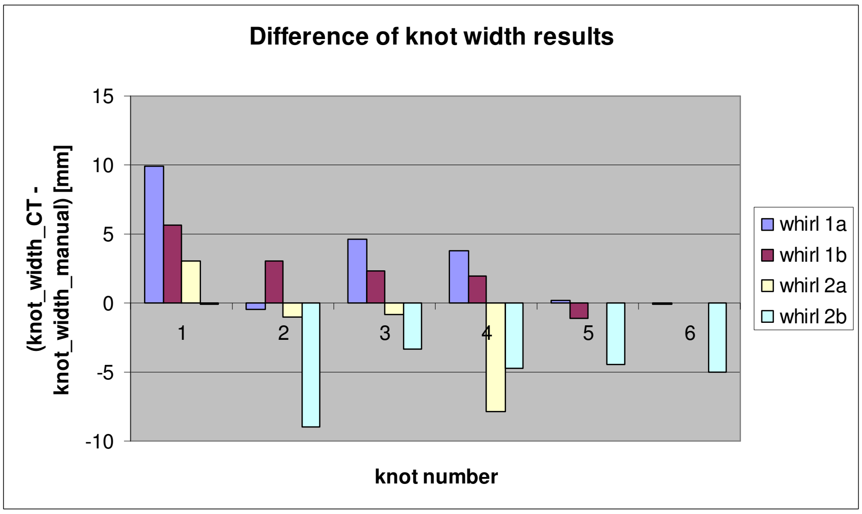


Figure 8: Difference between manual and CT measurement of the knot width

4 Discussion and Conclusion

Figure 4 shows that the direction of knots can be determined to a high precision. The smaller differences in Figure 5 are assumed to originate from the difference of the two measuring methods. In the reference measurement the measured angle of a knot is weighted equally for each slice. Changes of the knot direction near the pith, where the knot is small, can thus influence the reference value for the direction stronger. To define the direction of a knot in the CT reconstruction, the centroid of its three-dimensional shape was calculated. The approach implies that slices are weighted by their number of knot pixels. Thus slices, where the knot is small, will not effect the direction of the centroid as much as slices, where the knot is larger.

For the radial measurements a comparison was more difficult, because the manual measurements described the knots in the whole log, where the CT measurements only gave the shape in the heartwood. Figure 6 shows that the shape of the knot in the heartwood is quite accurate. Smaller differences result from wood structures with high density surrounding the knot. These structures are also difficult or even impossible to differentiate from the knot in the CT data by optical inspection and on the reference discs.

These structures also influence the width measurements, but the differences between the two measurements in Figure 7 cannot be explained just from this fact. Although the knot surrounding annual ring structure has a higher density for bigger knots and therefore might be classified as part of the knot, only the overestimations of the bigger knots in log 1 can be explained by that. The underestimations of the knots in log 2 can result from the lower amount of heartwood, because the real maximum width of the knots in this case is more likely in the sapwood. Therefore the manual measurement, which takes the maximum width in heartwood and sapwood, is higher than the maximum just taken from the heartwood part. But nevertheless from both logs the CT-knot-widths give a rough estimate of the real knot width.

In general this study shows that, at least for the reference material, the direction and size of the knots can be estimated with a high quality, using the three-dimensional shape detected from the CT images.

In a next step the results will be verified with a bigger amount of sawn timber. A shape estimate of the knots in the sapwood is also planned.

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