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Automatic knot segmentation in CT images of wet softwood logs using a tangential approach

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ABSTRACT

Computed Tomography (CT) is more and more used in forestry science and wood industry to explore internal tree stem structure in a non-destructive way. Automatic knot detection and segmentation in the presence of wet areas like sapwood for softwood species is a recurrent problem in the literature. This article describes an algorithm named *TEKA* able to segment knots even into sapwood and other wet areas by using parallel tangential slices into the log that enable to follow the knot from the stem pith to the bark. On each tangential slice, knot pith is detected, then knot diameter is estimated by analyzing gray level variations around the knot pith. A validation was performed on 125 knots from five softwood species. The CT slice resolution ranged from 0.4 to 0.8 mm/pixel with an interval between slices of 1.25 mm. Compared to manual diameter measurements performed on the same CT slices, the *TEKA* algorithm led to a RMSE of 3.37 mm and a bias of 0.81 mm, which is rather good compared to other algorithms working only in heartwood.

1. Introduction

The application of X-ray Computed Tomography (CT) to wood science and industry was investigated since many years. After the pioneer works of Taylor et al. (1984), Funt (1985) and Funt and Bryant (1987), numerous works have been conducted to develop algorithms to automatically detect wood features in CT images with a special interest for knots. (Longuetaud et al., 2012) presented a review of the literature about automatic knot detection algorithms. Recent works can be added to this review: Aguilera et al. (2012) (species not specified), Breinig et al. (2012) on Norway spruce and Johansson et al. (2013) for Scots pine and Norway spruce. In overall, algorithms for knot detection and segmentation are efficient on dried wood, but a recurrent problem mentioned in the literature is the presence of wet areas generally within sapwood. For many softwood species, sapwood has a much higher wood density than heartwood at fresh state (Polge, 1964) due to the higher water content of sapwood. Within fresh logs of these species, classical approaches based on gray level values are not efficient because fresh sapwood has almost the same density as knots.

Aguilera et al. (2012) is the continuation of an approach based on simulated annealing in deformable contours (Aguilera et al., 2008a,b). Using deformable contours for knot segmentation is an original approach that can work in presence of sapwood. However, in the examples of their experiments, only a very small part of the knots is included within sapwood. Moreover, the segmentation process is not fully automatic since the deformable model must be manually initialized and the method was not statistically validated.

Breinig et al. (2012) algorithm is a classical approach based on gray level thresholding. They first remove sapwood in the CT images in order to detect knots in heartwood only, based on a fixed gray level threshold corresponding to a density of 900 $kg\,m^{-3}$. Morphological operations are then used to improve the knot detection. The algorithm was designed to work within fresh heartwood but not within sapwood. Indeed, the method shows some weaknesses in presence of partly dried sapwood. A statistical validation was performed based on 55 knots from 55 cross-sections. The knots with very unclear border were avoided in the validation sample, which could artificially improve the accuracy results.

Until now, Johansson et al. (2013) are the only ones to propose a method designed for working in heartwood and in sapwood as well. Their algorithm is the continuation of Grundberg and

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Grönlund (1992) works. The algorithm is also based on images of concentric surfaces (CS) or cylindrical shells within the logs, following approximately annual rings. The main difference is that Johansson et al. (2013) have applied their algorithm on images of lower resolution than classical CT images obtained from medical scanners. The objective was to process images like the ones which would be obtained by a high speed industrial CT scanner. The knot detection is based on 10 CS with a minimum of five CS in heartwood. CS are thresholded in order to detect high density objects and then ellipses are fitted on these objects. Ellipses which can be matched through at minimum three consecutive heartwood CS are assumed to correspond to knots. Regression models for size and location of knots are fitted from the detections in heartwood and they are then used to generate sub-images in sapwood CS supposed to contain the knots. Computation of gray level standard deviations in rows and columns in these sub-images confirm or not the presence of a knot. If a knot is present they "try to find the position and size of it in the sub image using morphological dilation". This last step is not detailed. Since the authors write that the detection in sapwood succeeds only for "knots that have higher density than the surrounding sapwood", it may be supposed that knots are detected and measured by gray level thresholding. Given our images, a method based on a threshold could fail in many cases.

This paper presents an algorithm – named *TEKA* – designed for knot segmentation into wet logs in which sapwood can have a density similar to knot density. We chose to focus on the segmentation step. That means that we started from already defined "knot areas", i.e., angular sectors, radius range and slice interval framing each knot. *TEKA* is then able to separate the knot from sapwood or moisture areas within each knot area. Indeed, in our approach, we have assumed that detection (i.e., localization of knot areas) and segmentation (i.e., segmentation of the knot within each knot area) were two different steps. The algorithm could plug after any existing software able to achieve the detection step and to define knot areas.

Starting from a knot area, *TEKA* uses an original approach by looking at the log in a tangential view rather than the classical transversal view (i.e., CT slices or cross-sections). A tangential image is orthogonal to the CT slices and tangential with regard to annuals rings. Grundberg and Grönlund (1992) followed by Johansson et al. (2013) already presented a quite similar approach but based on concentric surfaces centered on the log pith (see above). The main difference is that our segmentation method is based on knot pith detection and analysis of gray level variations around the knot pith rather than on classical image thresholding. Furthermore, it was designed for working as well in heartwood and in sapwood. Validation results obtained on five softwood species are provided and discussed hereafter.

2. Materials and methods

2.1. Sampling

We developed and validated the algorithm based on 125 knots from 16 wet logs (12 trees) of five softwood species: four Douglas-fir logs (25 knots), three silver fir logs (29 knots), three European larch logs (26 knots), three Scots pine logs (20 knots) and three Norway spruce logs (25 knots). Logs were provided by Siat Braun sawmill (France).

The diameters of the logs ranged from 12 to 27 cm with a sapwood ratio ranging from 24% to 62% of the log radius.

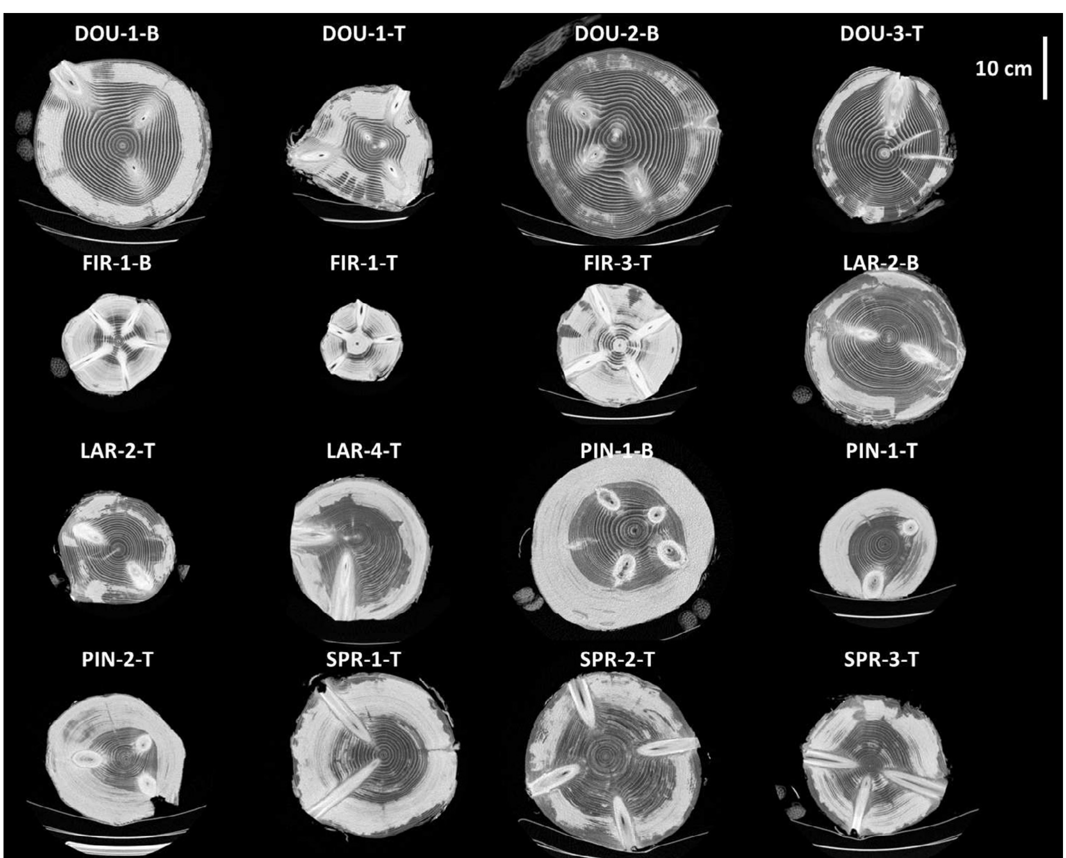

Fig. 1. Illustration of one CT slice per log in order to visualize some knots and the sapwood, as well as to obtain an information about the moisture content of logs. The three first letters of the log names identify the species, the following digit identifies the tree, the last letter indicates the stem bottom (B) or top (T).