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Automatic detection of the heartwood/sapwood boundary within Norway spruce (*Picea abies* (L.) Karst.) logs by means of CT images

Fleur Longuetaud *, Frédéric Mothe, Jean-Michel Leban

INRA, Equipe de Recherche sur la Qualité des Bois, UMR1092 Laboratoire d'Etude des Ressources Forêt-Bois (LERFoB), 54280 Champenoux, France[1]

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Abstract

An algorithm that automatically detects the boundary between heartwood and sapwood within fresh Norway spruce (*Picea abies* (L.) Karst.) logs was developed. Stacks of digital images of the internal structure of the logs were obtained through computed tomography. Boards, oriented in the longitudinal direction of the logs and passing about through the pith line, were reconstructed from stacks of images. The reconstructed boards were inspected by three operators who independently mapped the heartwood/sapwood boundaries using an image manipulation program. Their digitised mappings were collated and then sorted into two sets. One set signified close agreement between readings of the three operators, the other signified greater variation. The data sets were used as a basis for validation of the algorithm. The algorithm initially detected the pith location. Then, for the heartwood containing no knots, the boundary was detected by drawing (rasterising) 360 radii (with an angle of 1° between adjacent radii) from the pith to the first pixel whose intensity exceeded a given threshold. A post-processing was developed to separate knots in the heartwood from sapwood by longitudinal interpolations of the boundary. The automatically detected boundary was found to be in good agreement with the mappings of the operators (mean and median differences of 1.8 and 0.9 mm, respectively, where mappings of operators were concordant), especially at the bottom of the stems and for the oldest trees.

Keywords: Heartwood; Sapwood; Automatic detection; CT images; Norway spruce; *Picea abies*

1. Introduction

Sapwood, which is the active outer part of the stem, plays a major role in the vital functions of trees. It provides a pathway for water transport from roots to leaves and storage for metabolites. During the lifetime of a tree, sapwood gradually changes into heartwood which consists exclusively of dead, inactive cells. Details about the process of heartwood formation and about its properties can be found in Bamber (1976), Hillis (1987) and Taylor et al. (2002).

In the industrial context, knowledge about the distribution of heartwood and sapwood in trees can be useful as their physical and technological properties often differ in terms of colour (Münster-Swendsen, 1987; Espinoza et al., 2005),

* Corresponding author.
E-mail addresses: longueta@nancy.inra.fr (F. Longuetaud), mothe@nancy.inra.fr (F. Mothe), leban@nancy.inra.fr (J.-M. Leban).
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natural durability (Cruz et al., 1998; Björklund, 1999; Kärenlampi and Riekkinen, 2003), impregnation properties (Wang and De Groot, 1996) and moisture content (MC) (Fromm et al., 2001).

In the scientific context, e.g. from an eco-physiological point of view, the ratio of sapwood area and foliage biomass indicates the capacity of the sapwood to conduct water relatively to the demand in transpiration (Mäkelä and Valentine, 2001). In this context, the theory developed by Shinozaki et al. (1964a,b), known as the "pipe model theory", constitutes the basis of numerous studies. The main objective of such studies is to improve our understanding of the physiological processes that are involved in tree growth, in order to build growth and yield models, for instance.

Usually, the boundary between heartwood and sapwood can be assessed either visually directly on cross-sections through the observation of colour changes (either natural or obtained by translucence or staining processes; Münster-Swendsen, 1987; Rust, 1999) or through techniques of measurements, developed more recently and usually non-destructive, which enable visualisation of the boundary at fresh state based on a difference in MC between heartwood and sapwood (Fromm et al., 2001). These techniques can be: conductivity measurements by means of electrodes (Cermák et al., 1992; Bohner et al., 1993), microwaves (Johansson et al., 2003a,b), infra-red imaging (Arnerup, 2002; Gjerdrum and Høibø, 2004), radiography (Polge, 1964) and computed tomography (CT) (Rust, 1999; Fromm et al., 2001; Oja et al., 2001; Sandberg, 2002; Wilhelmsson et al., 2002).

CT measures density within objects. For instance, in fresh softwood logs, the measured densities (which depend on both wood density and MC) are usually greater in sapwood than in heartwood due to greater MC in the sapwood. CT is a powerful technique to acquire measurements of high spatial resolution within logs in a non-destructive manner. However, regarding the resulting large amount of data (stacks of CT images), the development of algorithms is necessary to process images automatically for the segmentation of heartwood and sapwood.

An algorithm to detect the boundary between heartwood and sapwood is described by Grundberg and Grönlund (1992) and Grundberg (1994, 1999) for CT images of Scots pine (*Pinus sylvestris*). The images are processed in the following way: a low-pass filtering, a thresholding and a gradient filtering. Then, radii are drawn and measured from the pith (semi-automatically detected) to the heartwood border, with an angle increment of 1°. However, the processing in the presence of knots is not described and the accuracy of the algorithm is not evaluated.

A study performed by Schmoldt et al. (1996, 1998, 2000) and He (1997), in which artificial neural networks (ANN) are used for the detection of wood characteristics on CT images, is also reported here as it describes an interesting approach. Although the first aim of the study is not the segmentation of heartwood and sapwood, this segmentation is tested for Yellow poplar (*Liriodendron tulipifera*). Indeed, Yellow poplar was the only species in the study by these authors for which sapwood was visible on CT slices. The ANN detects wood characteristics by sorting pixels into classes. Thus, it was necessary to add a new class corresponding to sapwood to the outputs of the ANN. However, as the segmentation between heartwood and sapwood is not the aim of this work, the method is not evaluated in this respect.

More recently, Espinoza (2005) and Rojas et al. (2006) also chose an approach by classification algorithms (two parametric supervised algorithms: a minimum distance and a maximum likelihood ones) to process CT slices of Sugar maple (*Acer saccharum* Marsh.). The purpose is to separate sapwood (of higher value) from coloured heartwood and other wood characteristics (knots, rot, splits and bark). The algorithm gives good classification results although overlaps between classes are observed. According to the authors, further research must be performed to assess the robustness of the algorithm on larger sample size with in particular, greater moisture content variations.

The objective of this study was to develop an entirely automatic algorithm for detecting heartwood and sapwood in stacks of CT images of freshly cut Norway spruce (*Picea abies* (L.) Karst.) logs. The greater MC in sapwood was used to distinguish it from heartwood.[2] As the images could contain knots, a robust and adaptative algorithm being able to work in the presence of knots was required. Particular emphasis was placed on validation of the method.

2. Materials and methods

2.1. Materials

In this study, logs coming from four Norway spruce stands of the Vosges mountains (North-East of France) were analysed. The stands were representative of three contrasted age classes with mean stand age ranging from 66 to 133

[2] In the case of Norway spruce, the heartwood cannot be distinguished from sapwood by eye as there is no natural difference in colour.