AUTOMATED DELINEATION OF TREE-RINGS IN X-RAY COMPUTED TOMOGRAPHY IMAGES OF WOOD

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ABSTRACT

In this paper, the authors present an original method for the automated recognition of tree-ring limits in X-Ray Computed Tomography images of wood. The method is based on two steps: tree-ring tagging, and tree-ring delineation. The first step is performed by analyzing the radial intensity profiles after locating automatically the pith, and the second step uses active contours which iteratively detect the different tree-rings, from the bark to the pith. In particular, the geometrical constraints included in the active contour algorithm allow getting coherent limits, without break or discontinuity. The method is robust enough to override the main artifact met in dendrology, as for example, nodes or splits and to deal with the very high variability of different tree species.

Index Terms — image processing, computed tomography, tree-ring, wood

1. INTRODUCTION

Tree-rings are the concentric circles visible onto the transversal slices of the trunk or the branches. Each ring is composed of two parts: the initial wood, produced in spring, which is soft and light, and its opposite, the final wood, made in autumn which appears hard and dark.

Counting and characterizing the geometry of tree-rings are essential to understand, model and assess the development of trees. In the wood growth studies, the width and the density of the tree-rings allow one to understand how is allocated the woody material in the bark and the branches, and to correlate the tree development with the climate parameters. In wood quality assessment, the width of the tree-rings is a strong determiner of the wood density, therefore of its mechanical properties or calorific ability.

The study of the tree-ring limits is then a crucial issue in dendrology, whereas it is not much described in the scientific literature. It is in general based on precise photographs of slices of trunk or branches. These last years, several algorithms have been proposed to assist the expert in the recognition of the pith or the sapwood and in the delineation of tree rings. For example, [3] is based on edge detection to find pixels that belong to the annual rings; in [6], the pith is first detected in order to perform an analysis of the radial intensity profiles; [8] includes computation of the 1st and 2nd degree derivatives to detect the annual ring borders; [9] combines morphological operators with thresholding to identify the ring zones. Some commercial software solutions as WinDENDRO (Regent) or LIGNOVISION (Rinntech) are also available to process wood photographs.

Nevertheless, using photographs requires slicing up a log which is time consuming and costly whereas to well understand the development of a trees species, the observations should be made on a very large number of samples. X-ray Computed Tomography may fulfill this requirement as the acquisition is performed on a complete log and numerous slices can be taken in some minutes. Of course, this implies to develop as automatically as possible algorithms to process such a large quantity of data. Moreover, the methods must be very robust with respect to the high variability of the CT image intensity (which depends on the wood damp, the width of rings or the contrast between the initial and the final wood).

These last years, new algorithms have been proposed to process CT images of wood. The authors were interested in the identification of different tissues as the pith [5] and the sapwood, or in the recognition of more complex structures as the tree-rings or cracks [2].

In this paper, we propose a new automated method to identify tree-ring limits in CT images of wood. The originality is based on tagging the transitions between successive tree-rings, and on the use of this tagging to reject "false rings" or to guide the delineation of "true rings". Then, the tree-rings are detected from the bark to the pith by successive applications of an active contour.

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2. PRESENTATION OF DATA

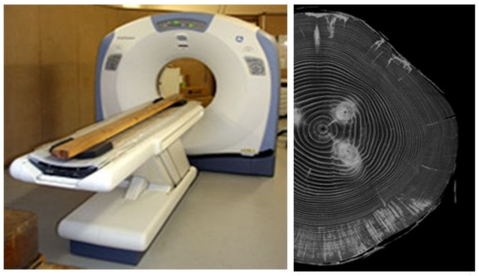


Fig. 1: *Left, the CT scanner of the Xylosciences platform. Right, a CT slice of a Jack Pine log.*

The CT acquisitions were performed on a 4-slice helical CT scanner GE BrightSpeed Exel which is part of the Xylosciences platform of the LerFOB laboratory (Fig. 1).

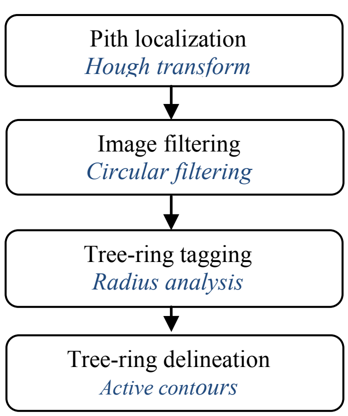
Acquisitions were performed with a tube voltage of 100 kVp and an intensity of 50 mAs with a helical pitch of 1. Image reconstruction was made by using a so-called *Bone* filter which enhances the contrast of radio-opaque structures.

The size of resulting images is 512×512 pixels with 1.25 millimeter width. The pixels are coded on 16 bits: the value of each pixel is given in an absolute scale called the Hounsfield unit scale which represents the absorption of the X-ray signal through the sample at the pixel location. It fluctuates from -2,000 to 1,500, and is represented by grey levels as shown in Figure 1. Tree ring limits appear as more or less concentric brighter circles in the image. In general, we can also see in the image a black radial line or portion which corresponds to a saw cut which is required in order that the wood log does not crack when it dries. Nodes appear as bright areas perturbing the geometry of rings

3. DESCRIPTION OF THE ALGORITHM

3.1. Overview

The opposite flowchart describes the different steps of the processing, from the image filtering to the tree-ring delineation. Each step is detailed below.



3.2. Pith localization

The pith is the central part of the wood around which are more or less centered all the rings. So, the pith center can be modeled as the center of concentric circles, even if in reality, the tree-rings are more or less circular and the pith is often shifted.

The pith center is localized by the Hough transform, well adapted to the detection of concentric circles and their centers into noisy images [7]. First, we apply a Sobel filter in order to detect the contours, in particular along the rings. Then, we perform a set of Hough transform by using circles of different diameters (from 5 to 100 pixels with a step of 5). This leads to different Hough-space images where the local maxima represent the potential centers of circles of the corresponding diameter. By summing all the Hough-space images and detecting the maximum, we extract the pixel which is likely to be the center of the maximum number of concentric circles.

Such simple algorithm works very well because the rings which are near the pith are in general very regular and circular. In the case of several piths, only the one with the maximal concentric rings will be detected which corresponds to the main branch or to the main pith (the others can be due to secondary splitting). At last, this method is very robust with respect to the saw cut.

3.3. Image filtering

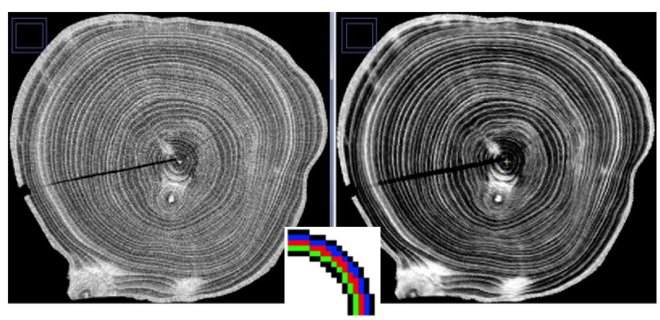


Fig. 2: Image filtering. *Left, the raw image of an Ash tree. Right, the circular filter enhances the tree-rings; Center, a representation of the discrete circle used by the circular filter.*

The aim of this step is to filter the noise or the intensity variations around the rings before identification and delineation. For this, we use a circular filter which is centered onto the pith. Each pixel of the image takes the average of its curvilinear neighborhood defined by the discretization of a circle given in [1]. As shown in Figure 2, it enhances the rings which are more or less circular whereas it averages the background noise.

3.4. Tree-ring tagging

The tagging step aims to give a quantitative indication on the transition between the rings which is defined at the interface bright (final wood)/dark (initial wood). A high variation of intensity means a clean limit between two consecutive rings whereas a low variation indicates a poorly marked limit. We compute the intensity derivative profile along the radii starting from the pith center (Fig. 3). Only the negative parts of the derivate profiles are kept which corresponds to the transition bright→dark and we obtain a series of peaks. Then, we assign to the pixel located at the center of the peak a value corresponding to the area of each peak. By this way, we tag the image with a probability of presence of a ring transition.

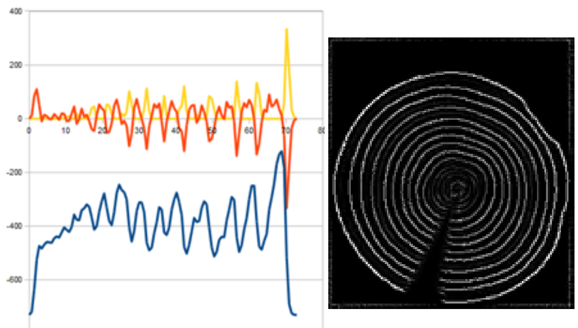


Fig. 3: tree-ring tagging. *Left: in blue, the intensity profile along a radius; in red, the derivative profile; in yellow, the tagging curve which gives the probability of a presence of a transition between two rings along the radius. Right: the tagging image of the Spruce presented in Fig. 6; each tag indicates a potential ring transition and its value is displayed in grey level.*

3.5. Tree-ring delineation

We use a circular closed active contour (also called "snake") to delineate accurately the limits of a tree-ring [4]. It is represented by a discrete set of n points Pi where P_0 is linked with Pn-1. The bark of the wood is detected by a simple thresholding and the active contour is initialized onto it. It deforms then towards the tags which are on the most external ring. After stabilization, the tags corresponding to this ring are erased, and the process is iterated again. Thus, the active contour converges on the next inner ring, and propagates gradually to the pith (Fig. 4).

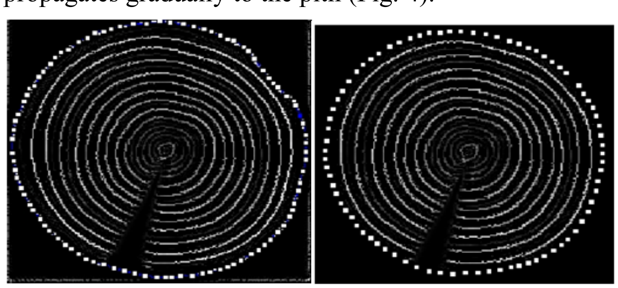


Fig. 4: delineation by active contours. *Left: the active contour is initialized along the bark of the Spruce presented in Fig. 5. Right: then, the tags of the bark are erased, and the active contour converges towards the first external ring.*

The 3 following forces are combined to produce a coherent displacement of the active contour.

3.5.1. Attraction force

The tags are used as attraction points. Each point P_i of the active contour is attracted by a force based on the distance to the tags Q_j located in its neighborhood and their values:

$$(1) \quad \mathbf{F_A} = \frac{1}{m}\sum_{j=1}^{m}\left(v(Q_j)e^{-4\frac{\|P_iQ_j\|}{r}}\frac{\mathbf{P_iQ_j}}{\|\mathbf{P_iQ_j}\|}\right)$$

where

- *v()* is the value of the tag
- *r* is the radius of the neighborhood
- *m* is the number of tags found in the neighborhood

3.5.2. Regulation force

The points of the active contour are maintained equidistant: this force manages the number n of points onto the closed contour. Each point P_i is adjusted according to its two neighbors P_{i-1} and P_{i+1} by the following expression:

$$(2) \quad \mathbf{F_r} = |k|\frac{\mathbf{X}}{\|\mathbf{X}\|} \quad \text{where}$$

- $k = \frac{\|P_{i-1}P_i\| - \|P_iP_{i+1}\|}{2}$
- $\mathbf{X} = \mathbf{P_{i-1}P_i}$ if $k > 0$, $\mathbf{X} = \mathbf{P_iP_{i+1}}$ if $k < 0$ and $\mathbf{X} = \mathbf{0}$ if $k = 0$

3.5.3. Bending force

To remain smoothly rounded, the active contour is maintained close to a second degree curve *C* defined by:

$$\begin{cases} x(t) = a_{11} + a_{12}t + a_{13}t^2 \\ y(t) = a_{21} + a_{22}t + a_{23}t^2 \end{cases}$$

For each point P_i, the coefficients a_{kl} are evaluated by the least squares method based on the 14 neighbors of P_i (the 7 previous and the 7 next). The orthogonal projection P_i' of the point P_i on *C* allows one to define the bending force as:

$$(3) \quad \mathbf{F_b} = \mathbf{P_iP_i'}$$

3.5.4. Description of the process

The displacement of each point P_i of the active contour is proportional to the sum of the previous forces:

$$(4) \quad \mathbf{F_i} = k_0(k_1\mathbf{F_A} + k_2\mathbf{F_r} + k_3\mathbf{F_b})$$

with k_0=3.5; k_1= k_3=0.2; k_2=0.4. These different coefficients have been fixed by experiments on a sample of 20 images composed of different tree species (Ash, Beech, Maple…).

The active contour iterates until the sum of displacements of all the points is inferior to 5 pixels and the tree-ring delineation stops when the active contour contains less of 15 points.

4. RESULTS AND DISCUSSION

About 40 images were successfully processed. The method is robust enough to override the main artifacts met in dendrology, for example the nodes or the splits (Fig. 5), and to deal with the very high variability of different tree species. It gives also consistent results around the saw cut. The accuracy of results is being evaluated by wood experts.

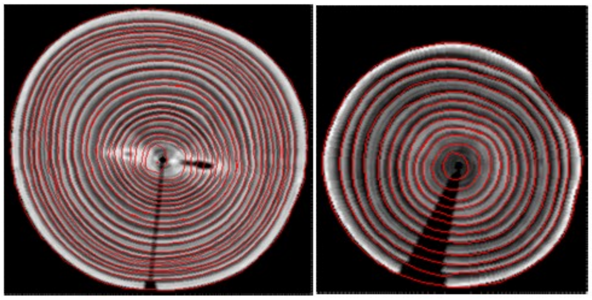


Fig. 5: tree-ring delineation. *The tree-ring limits are overlaid onto the images of* Ash tree *(left) and* Spruce *(right). Notice the consistency of the shapes of the rings in spite of the nodes, the splits and the saw cut.*

The implementation is realized in Java language. An image is processed in about 15 minutes on a computer with an Intel Core Duo 1,066 Mhz processor with 2 Gb of Ram.

Some aspects remain to be improved. In some cases the tree-rings overlap as shown in Fig. 6 and then, the common tags are erased when the first ring is delineated, preventing the second ring to be detected. In the presence of multiple piths or in the case of elliptic tree-rings, the tagging may be not enough accurate and complete, and the ring delineation becomes partial and incorrect.

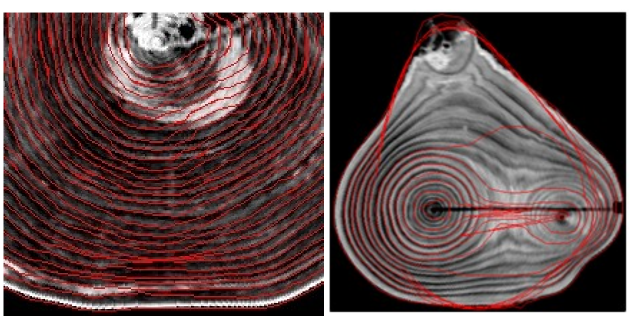


Fig. 6: the limits of the method. *Left: a close-up on Maple, presenting a tree-ring overlapping in the bottom central part. The active contours are locally mixed. Right: a bad ring delineation on Ash tree: the tagging step fails on the horizontal part of the elliptic rings because the Hough transform does not detect any circular shape Without any tag, the active contour will not be able to delineate the rings.*

Some improvements are already planned to avoid the pith localization step. We could delineate a first ring by using an active contour initialized along the bark. Then we could iteratively perform tag perpendicularly to the active contour in order to find features of the next tree-ring and run the active contour from its previous position.

5. CONCLUSION

We developed an automated method of tree-ring delineation in X-Ray CT images of wood. It is composed of four parts: pith center identification from Hough transform, image filtering using discrete circles, tree-ring tagging from radius profiles analysis and tree-rings delineation by active contours.

The first results produced from 4 different trees species are encouraging. The method is robust enough to override the presence of nodes or splits into the images. However, some issues still resist: for example, the multiple piths or the tree-rings overlapping. The improvement of the tagging step should be solving the first issue. The second should be the subject of a complementary study.

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