X-ray phase-contrast micro-tomography and image analysis of wood microstructure

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Abstract. A number of commercially important properties of wood depend on details of the wood micro- and nano-structure. CSIRO Forest Biosciences have developed SilviScan, an analytical instrument which uses a number of high-speed techniques for analyzing these properties. X-ray micro-tomographic analysis of wood samples provides detailed 3D reconstructions of the wood microstructure which can be used to validate results from SilviScan measurements. A series of wood samples was analysed using laboratory-based phase-contrast x-ray micro-tomography. Image analysis techniques were applied to the 3D data sets to extract significant features and statistical properties of the specimens. These data provide a means of verification of results from the more rapid SilviScan techniques, and will clarify the results of micro-diffraction studies of wood microfibrils.

1. Introduction

Important features of wood micro- and nano-structure include the presence and distribution of different wood cell types (tracheids, fibres, parenchyma, vessels) that constitute the structure and, on a smaller scale, the orientation of the cell wall cellulose microfibrils which give the wood its tensile strength and stiffness. A number of techniques can be used to analyse the micro-structural properties of wood, many of which are incorporated into the SilviScan[1] system developed by Robert Evans and his colleagues in the Forest Biosciences program at CMSE.

Two of the types of property that can be observed by SilviScan are the cross-sectional dimensions of wood cells, and microfibril angle variation obtained by x-ray scanning diffractometry. Analysis of wood sections can be used to extract information about the distribution of vessels and different types of wood cells, but the method relies on 2D cut sections which can suffer from surface damage. The measurement of microfibril angle and angular variation is likewise complicated because information on the microfibril orientations is entangled with variation in orientation of the wood fibres and with the variation in wood density.

X-ray phase-contrast micro-tomography is very well suited to the analysis of wood microstructure and provides valuable data for validation of the above analyses from SilviScan. Tomography enables the analysis of ‘sections’ throughout the volume of the wood without physical sectioning. Coupled with image-processing techniques developed at CSIRO Mathematical and Information Sciences it also opens the door to image analyses in 3D that have been previously restricted to 2D optical sections. Analysis of wood fibre orientations can also be carried out for comparison with SilviScan diffractometry data on microfibrils.
2. Data collection
We have collected 3D data on different wood samples and used 3D image analysis methods to extract quantitative information about wood microstructure, such as cell wall orientations, and the distributions of different cell types.

Our micro-tomographic data were collected using the X-ray ultra-Microscope (XuM), an instrument developed by CSIRO and XRT Ltd. This instrument makes use of inline phase-contrast to improve contrast of low density materials[2]. It has imaging resolution <100nm at the highest magnification, and tomographic resolution down to 2μm or 0.5 μm with image alignment[3]. Polychromatic radiation was used, with an average energy of 8keV.

X-TRACT[4] software was used to process and reconstruct the data including phase retrieval[5] of the phase-contrast images prior to tomographic reconstruction. Figure 1 below shows a selection of reconstructed cross-sections from different samples with different wood structures.

Figure 1 – Tomographic cross sections of 4 wood samples showing the variations in structure between different wood types. From left: bamboo; poplar; eucalypt and pine.

3. 3D Analysis
Two types of 3D analysis were performed on these datasets. The first was the extraction of gross features of the structure using mathematical morphological techniques and the second was extraction of variation in the cell orientations using a skeletonisation algorithm.

For the first of these analyses a low-magnification dataset of a eucalypt sample was used. Mathematical morphological methods[6] were used to extract specific features of the wood microstructure, namely vessels (large vertical channels), rays (narrow horizontal parenchyma cells) and longitudinal parenchyma cells (functional cells close to vessels in this species). The results are shown below in figure 2 including the rendered original 3D data and a rendered view of the segmented 3D data showing large vessels and horizontal rays (longitudinal parenchyma cells omitted for clarity). The rays are incompletely resolved in this example, and therefore appear to be discontinuous.

Figure 2. left: Rendered view of 3D tomographic reconstruction of a eucalypt sample; right: rendered view of segmentation of part of the dataset showing vessels (large vertical channels) and rays (narrow horizontal cells).
The next step was to extract information on the variation in orientation of the cell axes. The dominant cells (fibres) run vertically in the tree and it is the variations in the orientation of these cells that is potentially most significant in affecting microfibril diffractometry data. For this analysis we used two higher magnification datasets of eucalypt and pine respectively. The central axes of the fibres and ray cells were extracted from the reconstructed data using a skeletonisation algorithm[7] as shown for the pine specimen in figure 3.

The fibres (pine tracheids are also referred to as ‘fibres’ in this report) are the main body of cells in the wood and run approximately parallel to the trunk or branch axis and these can be seen running roughly vertically in the skeleton image. Analysis of the generated skeletons was carried out to extract the variation in the orientation of these cells in the tangential and radial directions in the tree. The angular variation in degrees for both wood types is shown in figure 3 for both radial and tangential orientations. The standard deviations (sigma) values from these data (shown on plots) indicate that the variation in orientation is greater in the radial direction than in the tangential direction for both wood types, and that the variations are greater in the eucalypt sample relative to the pine sample.

![Figure 3 –from left: rendered view of pine sample; extracted pine cell-axis skeleton; normalised plots of fibre orientation variation for pine and eucalypt samples in the radial and tangential directions.](image)

### 4. Conclusions
We have demonstrated the use of x-ray phase-contrast tomography to produce wood microstructure data of sufficient quality for extraction of details of gross and fine features. Future work will focus on the use of angular variation data to refine the results of x-ray diffractometry studies of microfibril angle from SilviScan and the improvement of morphological and other image analysis methods for extracting and categorising a range of features in wood datasets.

### References
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