

WOOD SHRINKAGE COEFFICIENT AND DRY WEIGHT MOISTURE CONTENT ESTIMATIONS FROM CT-IMAGES

Lars HANSSON

Assoc. Prof. – Luleå University of Technology, TVM
Div. of Wood Science and Engineering, Wood Physics
Address: LTU Skellefteå, SE-93187 Skellefteå–Sweden
E-mail: lars.hansson@ltu.se

Aalesund University College
Faculty of Engineering and Natural Sciences
Address: Larsgårdsveien 2, N-6025 Aalesund–Norway
E-mail: laha@hial.no

Bengt-Arne FJELLNER

Luleå University of Technology,
Professional Support, Div. VSS-ITS,
Address: LTU, SE-97187 Luleå–Sweden
E-mail: bengt-arne@ltu.se

Abstract:

The aim of this work was to try out an algorithm for estimating wood shrinkage coefficients from X-ray computed tomography images. The maximal amount of shrinkage that could occur from a green wood to oven-dry wood condition in the tangential and radial directions of the annual growth rings as well as longitudinally along the grain is expressed as a fraction of the green dimension. To estimate the shrinkage coefficients from tomography images, the wood test pieces in green state and oven-dry condition were scanned. By using an image registration algorithm, the dry wood image was thoroughly transformed to the shape of the green wood image, and the shrinkage coefficients could then be estimated. In order to try out the algorithm for moisture content calculation, a wide range of test material with different density, moisture content and size was used in the test. The material was from Pine wood, where the pieces were cut from different parts of wood logs, namely sapwood, pure heartwood, and a combination of sapwood and heartwood. The result from this transformation was compared to a tabulate shrinkage coefficient and showed a satisfactory outcome. The results show also that this method can be used to calculate the dry weight moisture content of wood from computed tomography (CT) images in a satisfactory way. The method requires wet and dry images of a wood piece. 'Dry image' means that the wood must be dried to zero dry weight moisture content before CT-scanning the image.

Key words: CT-scanning; image processing; shrinkage coefficients.

INTRODUCTION

Wood, like many organic substances, expands and shrinks with changes in humidity. However, this occurs only when the amount of water inside the wood is below a certain point, at which all free water has been removed from the cell cavities. This point is called the fibre saturation point (fsp). Below this point, swelling occurs when the amount of bound water in the wood cells increases, while shrinkage takes place when the amount of water in the wood cells decreases. This dimensional change occurs in three directions: tangential to the growth rings, radially from the pith outwards, and longitudinal. The dimensional change is greatest in the tangential direction, and then radially, and the dimensional change in the longitudinal direction is so small that it usually is neglected.

In order to make an elastically deformed image to look as similar as possible to another image, an algorithm (UnwarpJ) for a standard elastic registration could be used, (Sorzano *et al.* 2005). This algorithm assumes that one of the images is an elastically deformed version of the other, where the elastic fields are expressed in terms of B-splines. A spline curve is a sequence of curve segments that are connected together to form a single continuous curve and the word spline comes from the ship building industry, where it originally meant a thin strip of wood which draftsmen would use like a flexible French curve. Furthermore, this algorithm calculates the elastic deformation field through the minimization of an energy functional with three terms: the energy of similarity error between both of the images (represented by the pixelwise mean-square distance), the error of the mapping of soft land marks, and a regularization term based on the divergence and curl of the deformation to ensure its smoothness, (Sorzano *et al.* 2005). This algorithm for elastic and consistent image registration was developed as a plug-in for the software ImageJ (Image processing and analysis in Java). By using this algorithm, computed tomography (CT)-images of warped biological material can be matched to target CT-images. This approach has been used by (Hansson *et al.* 2005, 2006) and (Lundgren *et al.* 2006) on CT-images of wood to compensate the images for shrinkage and deformation. A new function that incorporates a factor of the deformation field consistency is presented in (Arganda-Carreras *et al.* 2006), Arganda-Carreras *et al.*, considering two transformations at the same time, direct and inverse. This algorithm (bUnwarpJ) for elastic and consistent image registration was also developed as a plug-in to the software ImageJ and has been applied to matching CT-images obtained from wood pieces, (Hansson 2008, Watanabe *et al.* 2012), and for matching micro CT-images from dental composites, (Chiang *et al.* 2010).

The aim of present paper is to describe the use of the generated displacement information directly from an image registration algorithm (Arganda-Carreras *et al.* 2006) to compute the shrinkage coefficients by transforming and scaling the density values, and then calculating the dry weight moisture content (mc) from these values. This approach is different than that of (Watanabe *et al.* 2012). Instead of using the displacement information directly to compute the shape changes, they used special software for digital image correlation, (Pan *et al.* 2009) to compute the local displacements in the images.

MATERIAL AND METHODS

From the image registration algorithm, (Arganda-Carreras *et al.* 2006), the deformation transformations are obtained. The transform information contains coordinates for the corners of the new area depicted, i.e., the deformed area. The new area depicted is enclosed by a closed polygonal chain, i.e., a finite sequence of straight line segments, where the segments are called its edges. Furthermore, a point where two edges meet is a vertex of the polygon. The software, General Polygon Clipper (GPC), designed for computing the results of clipping operations on sets of polygons, (Murta 2011) was used. This software uses a polygon clipping algorithm which descends from Vatti's polygon clipping method, (Vatti 1992). The basic idea used in polygon clipping is that a four sided polygon is represented by four vertices, P , (Fig. 1).

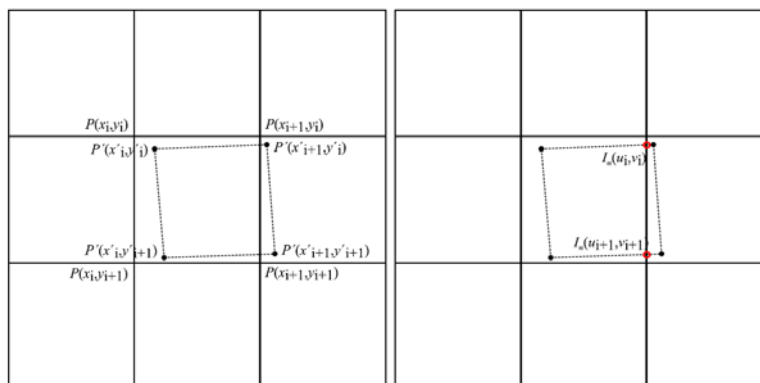


Fig. 1
Example of a clip polygon.

In this case, the points are the transformed coordinates generated from the image registration algorithm, (Arganda-Carreras *et al.* 2006). On each of the polygons, tests are performed. If the polygon intersects the window frame, the intersection points I_m (Fig. 1), where m is the number of intersection points, is stored. This process is repeated for all the edges of the polygon. Furthermore, the areas which are formed by the polygons between transformed coordinates or intersection points or a combination of the different points in each window frame, are given by:

$$(A_0)'_{i,j} = \frac{1}{2} \sum_{k=0}^3 (x_k y_{k+1} - x_{k+1} y_k), \quad (1)$$

where $(x_k$ and $y_k)$ are the coordinates for the vertices of the polygon that encloses the area in each window frame. If the total area spanned by the transformed coordinates is defined to be the total dry area, and the total area spanned by the window frame coordinates is defined to be the wet area $(A_X)_{i,j}$, then the equation for the shrinkage factor

$$\beta_{V,(X \rightarrow 0)} = \frac{V_X - V_0}{V_X}, \quad (2)$$

where V_X and V_0 are, respectively, the volume in an mc condition between fsp and zero mc and at zeros mc, can be written for each pixel as:

$$(\beta_{V,(X \rightarrow 0)})'_{i,j} = \frac{(A_X)_{i,j} - (A_0)'_{i,j}}{(A_X)_{i,j}}, \quad (3)$$

if the axial length of the boards is assumed to not change during the shrinkage. The scaled density value after the registration is calculated for each window frame by summing the product of the density value and the areas formed by the polygons between transformed coordinates or intersection points or a combination of these:

$$(\rho_{0,0})_{i,j} = (\rho_{0,0})'_{i,j} \left(1 - (\beta_{V,(X \rightarrow 0)})'_{i,j} \right) = (\rho_{0,0})'_{i,j} \frac{(A_0)'_{i,j}}{(A_X)_{i,j}}, \quad (4)$$

where $(\rho_{0,0})'$ is the dry density value from the registered image. By using the definition for the mc:

$$(X)_{i,j} = \frac{(m_X)_{i,j} - (m_0)_{i,j}}{(m_0)_{i,j}}, \quad (5)$$

and the definition of the scaled density, the mc can be written for each pixel as:

$$(X)_{i,j} = \frac{(\rho_{X,X})_{i,j} - (\rho_{0,0})_{i,j}}{(\rho_{0,0})_{i,j}}. \quad (6)$$

In order to try out the algorithm for the shrinkage coefficients and mc calculation, a wide range of test material with different density, mc and size was used in the test. The material was selected from Pine wood. The pieces were cut from different parts of the wood logs, namely solely sapwood, pure heartwood and a combination of sapwood and heartwood. To estimate the dry weight mc, samples with a 20mm thickness were dried in the oven at a temperature of 103°C for around 24 hours and the weight was measured before and after drying, according to ISO 4470. Furthermore, the test pieces were CT-scanned in the middle with a slice width (W) (Fig. 2) of 10mm, before and after drying. The total number of test samples was 43.

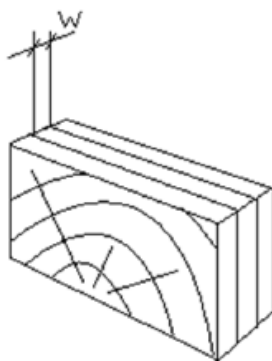


Fig. 2
Slice width (W) in the wood specimen.

By using the image registration algorithm, the scanned CT-images for all test pieces were transformed, the shrinkage coefficients were determined by transforming and scaling the density values, and then the dry weight mc was calculated from these shrinkage values (Fig. 3).

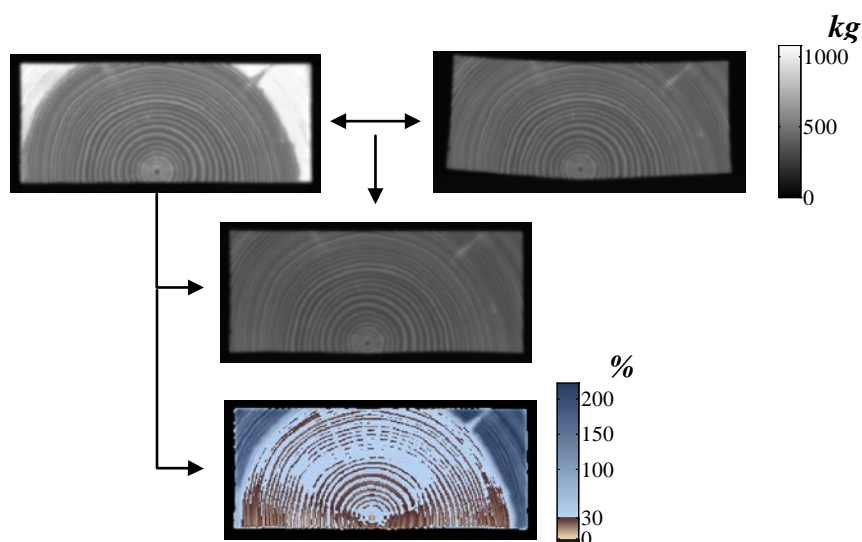


Fig. 3
Elastic registration of pine specimen.

The shrinkage coefficients calculated from the transforming were compared to tabulated values (Boutelje 1989). Furthermore, the estimated dry weight mc was compared to the results from the algorithm. In order to interpret the information obtained from the measurement and calculation, classical paired difference statistical tests were used.

RESULTS AND DISCUSSION

In the statistical test between the mc values from the algorithm and the dry weight method, the test-statistic value was calculated at around 0.0138. The low test-statistic value means that the null hypothesis is valid with a high probability and shows that no significant difference exists between the results. The dry weight mc was between 0.19 and 1.62. Furthermore, in the statistical test between the shrinkage coefficients from the algorithm and the tabulated values, the test-statistic value was calculated at around 0. The low test-statistic values mean that the null hypothesis is valid with a high probability and show that no significant difference exists between the results. The result from the statistical test shows a satisfactory outcome, which means that the algorithm is a very good tool for calculating the shrinkage coefficients and dry weight mc from CT images.

REFERENCES

- Arganda-Carreras I, Sorzano C, Marabini R, Carazo J, SolorzanoOrtiz-de C, Kybic J (2006) Consistent and Elastic Registration of Histological Sections Using Vector-Spline Regularization, in *Computer Vision Approaches to Medical Image Analysis*, Beichel, R. and Sonka M., eds. (Berlin: Springer), pp. 85-95
- Boutelje JB (1989) Träfakta. Träteknikcentrum, Stockholm. ISBN 91-970513-3-0
- Chiang YC, Hicel R, Lin CP, Kunzelmann KH (2010) Shrinkage vector determination of dental composite by CT images, *Composites Science and Technology* 70:989-994
- Hansson L, Lundgren N, Antti AL, Hagman O (2005) FEM Simulation of Heating Wood In an Industrial Microwave Applicator, in *10th International Conference on Microwave and High Frequency Heating*: pp. 415-418
- Hansson L, Lundgren N, Antti AL, Hagman O (2006) Finite element modeling (FEM) simulation of interactions between wood and microwaves, *Journal of Wood Science* 52:406-410
- Hansson L, Antti L (2008) Modeling Microwave Heating and Moisture Redistribution in Wood, *Drying Technology* 26:552-559
- Lundgren N, Hansson L, Hagman O, Antti AL (2006) FEM Simulation Of Interactions Between Microwaves And Wood During Thawing, *AIP Conference Proceedings* 834:260-267
- Murta A (2011) A General Polygon Clipping Library; <http://www.cs.man.ac.uk/~toby/alan/software/>
- Sorzano C, Thévenaz P, Unser M (2005) Elastic Registration of Biological Images Using Vector-Spline Regularization, *IEEE Transactions on Biomedical Engineering* 52:652-663
- Pan B, Qian K, Xie H, Asundi A (2009) Two-dimensional digital image correlation for in-plane displacement and strain measurement: a review, *Measurement Science and Technology* 20:062001
- Vatti BR (1992) A generic solution to polygon clipping, *Commun. ACM* 35:56-63
- Watanabe K, Lazarescu C, Shida S, Avramidis S (2012) A Novel Method of Measuring Moisture Content Distribution in Timber During Drying Using CT Scanning and Image Processing Techniques, *Drying Technology* 30:256-262