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An interactive computer vision system for tree ring analysis

S. Subah[1,*], S. Derminder[1] and C. Sanjeev[2]

[1]School of Electrical Engineering and Technology, and
[2]Department of Forestry and Natural Resources,
Punjab Agricultural University, Ludhiana 141 004, India

Tree rings (growthing) analysis provides useful information about the age of a tree and the past climatic conditions. Analysis of tree rings manually is a herculean task and requires a domain area expert. The present work proposes a soft technique to analyse tree rings. Effective canny edge detection approach was utilized to process high-quality digital images of tree rings. The developed program successfully performs interactive tree-ring image analysis with MATLAB Image Processing Toolbox. It generates information about the width of earlywood and latewood of the growth ring. The information generated may be further utilized by domain area expert to deduce the age of a tree. The development of such a system will ease the human analysis efforts.

Keywords. Canny edge detection, digital image processing, pixel labelling, tree rings.

DENDROCHRONOLOGY was developed during the first half of the 20th century, by astronomer A. E. Douglass, founder of the Laboratory of Tree-Ring Research at the University of Arizona, USA.

Each year, new cells are formed in a tree. These cells are arranged in concentric circles called annual growth rings, which show the amount of wood produced during one growing season. In summer, dark wood also known as latewood is produced because growth is slow, whereas in spring growth is fast and light wood also known as earlywood is produced. An alternate layer of light and dark wood appears on the cross-section when a tree is cut down. One year of growth is therefore represented by a ring consisting of a light part (earlywood) and a dark part (latewood). The older rings are near the centre of the tree. Width of a growth ring depends upon duration of growing season of the tree. The study of tree growth rings provides a glimpse of the past climatic conditions.

The automation of analysis of tree rings requires image analysis and processing. The task is difficult as the images contain high levels of noise. The appearance of tree rings has a greater contrast when the tree grows in an environment where climate is influenced by seasonal weather change; for example, temperate-zone tree rings compared to tropical-zone tree rings. Therefore, seasonal changes cause the tree to grow at different rates.

*e-mail: subah-coaeseeit@pau.edu

An interactive method for tree-ring width determination was developed by Rigozo *et al.*[1] using a high-resolution scanner and a personal computer. Interactive Data Language (IDL 5.0) environment was used to develop a program to process scanned tree-ring images. The developed program enhanced the ring contrast and produced ring-width time series. The images were scanned to resolution above 900 dpi and saved in bitmap file format (.bmp). The operation was performed by clicking the mouse left key on the centre (pith of the tree ring) the grey-scale image as the initial position. Successive clicks were made on every ring. The positions were recorded and tree ring width was calculated by subtracting two successive ring positions. To eliminate the presence of false rings and absence of some rings, time series was obtained. It represents every tree by digitizing more than one image per sample and taking the mean of widths corresponding to every ring for the same year. This is a simple and low-cost method and is best implemented when tree rings are not so close to each other. Generalized Hough transform technique was proposed by Cerda *et al.*[2] for tree-ring analysis. It is based on non-analytical shapes instead of assuming certain shapes. It is similar to manual techniques followed by experts, and requires two parameters for its implementation. The first parameter is the centre of wood disc (pith) and the second is a polygon (convex or not) that represents the perimeter. The steps involved are filtering, accumulation and selection of the rings. The centre is automatically obtained but perimeter was asked by the user. To give an idea of the final performance, the average time to process one wood disc was 172 s: 46% of this time for the accumulation, 18% for the Voronoi computation, 12% for the centre and filtering stage, and the rest was spent in reading and in the transformation operations such as RGB to HSV conversion.

WinDENDRO[3] is a semi-automatic image analysis system specifically designed to measure width of annual tree ring. It is semi-automatic because the user indicates from where to measure rings on it by creating ring paths. This is mature and robust system that is regularly updated. Vaza *et al.*[4] developed an automatic visual system for growth ring analysis using automatic scale selection for ring detection. There exist other well-documented programs and systems for tree ring analysis[5,6]. Various edge detection techniques have been compared in general[7] and with reference to images of tree rings[8]. The techniques compared are Sobel, Prewitt Operator, Roberts and canny edge detection. Comparison of the results was done on parameters like error rate, better edge detection in noise and optimization. On the basis of the result of these comparisons, canny technique is more suitable for the first step of detecting rings of all types using image processing. The best methods are required to solve the challenges of tree ring analysis like noise, missing true rings, detection of false rings, accuracy and responsiveness. The tree ring image analysis is also carried out using active contours and gradient operator[9]. Image analysis of tree rings is significant in cross-dating and cross-sectional interpolation[10,11].

The present communication proposes a soft technique to analyse tree growth rings. Effective canny edge detection approach has been utilized to process high-quality digital image of tree rings. The developed program successfully performs interactive tree-ring image analysis with MATLAB Image Processing Toolbox, and the results are comparable with those of domain expert.

The proposed system is used to analyse tree rings. This commonly involves measuring distance between ring boundaries. The most important aspect of this study is to detect tree rings boundaries with processing of the high-resolution image of tree disc. The tree smooth disc sample is prepared using precision grinder and the high-resolution image is chosen (clicked). The resolution and size of the image need to be balanced to obtain the required details. The analysis will depend upon image resolution; it will take less time for low-resolution image, but fewer rings will be detected. The platform used for image processing is MATLAB Image Processing Toolbox[12]. Various well-known methods of image processing are used to extract growth rings from ring image data. The following steps are implemented in the software to analyse tree rings.

The sample is prepared using precision grinder and a high-resolution image is obtained. The image is uploaded onto the proposed system. Both colour and b/w images are supported by the software.

To convert RGB image into greyscale image, the following equation is used

$$Y = 0.2989{*}R + 0.5870{*}G + 0.1140{*}\mathrm{B}. \quad (1)$$

To decrease the noise, and the image is convolved with a Gaussian filter.

Default value of hsize = [5, 5],
Standard deviation sigma = 2.

where hsize is a vector specifying the number of rows and columns in the filter.

An abrupt change in colour or brightness is known as edge. The difference in colour or brightness that occurs between latewood and earlywood forms an edge. Tree ring detection is done using an algorithm. Edge-detection algorithm is applied on the filtered image to observe and detect tree rings in an effective manner. On the basis of earlier studies[13], the canny edge detection algorithm is considered best for detecting tree rings. This algorithm is used to get well-connected edges. It is an optimal and multistage edge detection algorithm that consists of the following steps:

(i) To calculate gradient and magnitude of input image.

$$|G| = \sqrt{(G_x^2 + G_y^2)}, \tag{2}$$

$$\theta = a\tan(G_y/G_x), \tag{3}$$

G_x and G_y are the X and Y directional derivatives at the considered point.

(ii) Non-maximum suppression: Here grouping of edge directions takes place as follows – [0, 45], [45, 90], [90, 135], [135, 180], [180, 225], [225, 270], [270, 315], [315, 360]. Later suppression of non-maximum pixels along the norm of edge is done using edge direction information.

(iii) Threshold with hysteresis: Canny algorithm needs two key parameters: a high threshold value and a low threshold value. The high threshold value marks edges that are definitely strong edges. In this software default threshold values used in proposed system are as follows

Default threshold is: [0.01 0.15].

Low threshold < high threshold < 1.

The formation of tree rings is a natural phenomenon. Prior shape of rings and centre of rings cannot be assumed. While plotting coordinates, two parameters are required. These are coordinates of centre of tree rings and point at the circumference of tree disc. The latter can be plotted in any direction. Usually tree ring analysis is carried out by recording width in four or eight directions of wood disc. The x-coordinates and y-coordinates of the centre point and outer point are obtained. The image is treated as a grid of discrete elements, ordered from top to bottom and left to right.

The intrinsic coordinates (x, y) of the centre point of any pixel are identical to the column and row indices for that pixel.

The output of the canny edge detection algorithm is a binary image. The detected edges represent the tree rings. Intensity of pixel is 1 at the point where the edge is detected by the algorithm. The intensity of the pixels along the path between these two points is calculated. Pixel labelling is done at the point where intensity of the pixel is 1.

The internal appearance and growth pattern of the tree rings observed is given an approximate value of ring count. The edges labelled are twice in number than the true count of rings. Occasionally, a tree can produce multiple or false rings which can alter the true value of the number of growth rings.

The coordinate values of pixels with intensity 1 are saved. The radius of the detected edges from the centre is calculated using the Euclidean distance formula given in eq. (4) below.

$$\text{pix}_1 = [x_1, y_1], \quad \text{pix}_2 = [x_2, y_2]. \tag{3}$$

$$\text{Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}. \tag{4}$$

The radius of the rings is calculated in millimetres. The result is exported to an excel sheet and information is saved in the same. This information can be manipulated for further analysis. The labelling of rings is useful in observing the lighter spring wood and darker summer wood.

Ring completion is carried out in binary image. In case of broken and incomplete ring edges, ring completion is done. The initial and final points are plotted by the user. The intensity of pixel coordinates of the binary image lying along the path between the initial and final points is changed from 0 to 1. There is slight deviation because of the coordinate values are rounded-off.

The proposed software provides a semi-automated and interactive platform for tree ring analysis using high-performance MATLAB Image Processing Toolbox. Canny edge detection algorithm detects boundary of earlywood–latewood transition and latewood–earlywood transition. Pixel labelling is used for marking identified edges. The number of edges detected and labelled is approximately twice that of the actual count of annual rings. The annual ring width is the sum of the widths of earlywood and latewood. The width of annual rings (mm) can be calculated with processing of data exported to an excel sheet by the proposed system. These data can be utilized to observe and predict tree growth conditions. Post-processing of data is required to yield the necessary information. The data provides approximate widths (mm) of earlywood and latewood (mm). The total growth for one year is identified by the width of the annual ring. There is the possibility of production of false rings due to disease, injury, frost, damage, etc. So, ring count will not always indicate the exact age of a tree. Accuracy, error rate and reliable measurements are the functions of image selection, contrast between earlywood and latewood, and resolution of the image. Table 1 shows results for four directions, i.e. [0 90] [90 180] [180 270] and [270 360].

For validation of the results, two different samples of chir pine (*Pinus roxburghii*) were prepared. Figure 1 *a* and *b* shows the high-resolution images of these samples. Figure 2 *a* and *b* shows the number of edges detected by the developed software in first (20) and second (49) sample respectively. It indicates that the first sample has 10 (one half of the number of edges) growth rings and the second sample has approximately 24/25 rings. Domain expert has identified 11 and 28 growth rings in first and second sample respectively. The percentage of error in first and second sample is found to be 9.09 and 14.28 respectively. Table 1 shows the width of different growth rings for the first sample.

Table 1. Radius (mm) from the centre along four directions for the first sample

Ring number	0°–90°	90°–180°	180°–270°	270°–360°
1	2.06	2.24	2.24	1.87
2	7.29	7.10	7.48	6.73
3	11.78	11.59	12.34	11.59
4	13.28	13.09	13.47	13.09
5	17.02	17.21	16.46	16.46
6	18.52	18.33	17.96	17.96
7	22.68	20.20	18.70	21.32
8	25.63	22.45	19.83	23.57
9	26.75	25.06	22.82	25.06
10	29.74	26.19	23.94	27.31
11	34.61	29.56	26.19	31.08
12	36.10	35.17	30.68	32.92
13	42.09	36.29	31.80	38.16
14	43.59	42.65	36.66	39.66
15	50.70	44.15	37.79	45.27
16	52.19	50.13	43.40	46.39
17	57.43	51.26	44.90	51.26
18	58.93	56.12	49.76	52.75
19	64.92	57.62	50.88	57.24
20	–	62.86	56.50	60.99

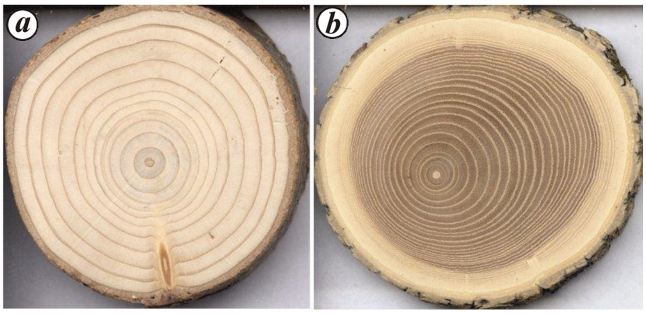

Figure 1. Images of (***a***) first sample and (***b***) second sample.

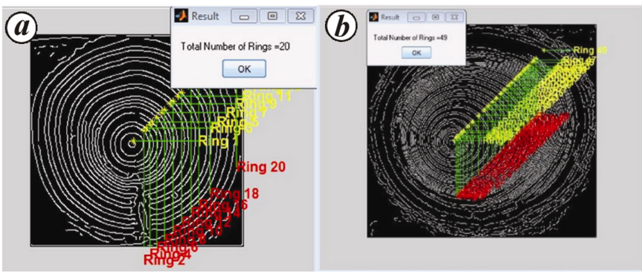

Figure 2. Number of rings detected for (***a***) the first sample, and (***b***) the second sample.

Thus, in the present work a simple and rapid system is proposed to analyse tree ring count and width. The data on ring width are exported to an excel sheet. They consist of distance of earlywood and latewood from centre. This information can be further processed and used by the domain expert to observe pattern of tree growth rings[14,15] and the past climatic conditions. The pixel labelling makes it easy to record and understand the information generated. This system is more accurate with samples in which tree rings are clear and are not too close to each other. For samples with close rings, the proposed system results are not accurate but acceptable.

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