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Tree Ring Analysis Using Image Processing Techniques: A Survey

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Abstract. Image processing techniques are efficiently utilized in diverse real-life areas. Tree rings are warehouse of information concerning the tree age and past climatic conditions, but analysis of this information is a difficult process and requires high level of expertise. Researchers thus have utilized image processing techniques for effective automation of the system. An attempt has been made in the manuscript to summarize the pros and cons of studies that mainly focus on different aspects of tree ring analysis. The performance of techniques is basically analyzed to recognize those that can be applied on different tree rings for analysis. Discovering various acceptable techniques, the manuscript mainly highlights numerous points of consideration. The survey presented in manuscript would be helpful to researchers to get understanding of machine vision applications for tree ring analysis.

Keywords: Tree ring analysis, Dendrochronology, Image processing

1 Introduction

Dendrochronology is the scientific technique of the analysis of tree rings patterns, also refers as growth rings [1]. In dendrology, the study of tree rings is general task. New cells formation occurs in tree every year. The cells form concentric circles known as annual growth rings. This ring indicates the wood quantity production in the growing season. In spring the expansion is fast, earlywood production occurs; where as in summer the latewood term is used for dark wood as expansion is slow. In the cross section of wood the different layers of dark and light wood emerge. Growth during one year is represented by light and dark part of wood. Near the pith of the tree, older rings appear. Growth ring width mainly depends upon the period of tree growing season. The past climatic conditions information can be obtained from observing tree growth rings. So, to study different parameters a system is required which automate the task of tree rings analysis. However there are some challenges such as image contains different noise levels. As tree grow in different seasonal weather conditions, tree rings appearance has larger contrast. Cross-section view of tree rings is represented in Fig. 1. Rings mainly provide the information regarding tree age, forest densities, and historic climate conditions. And also helps to identify flood and drought over different time span that provides economical advantages in the field of agriculture [2].
Main steps in the general architecture for the analysis of tree ring:

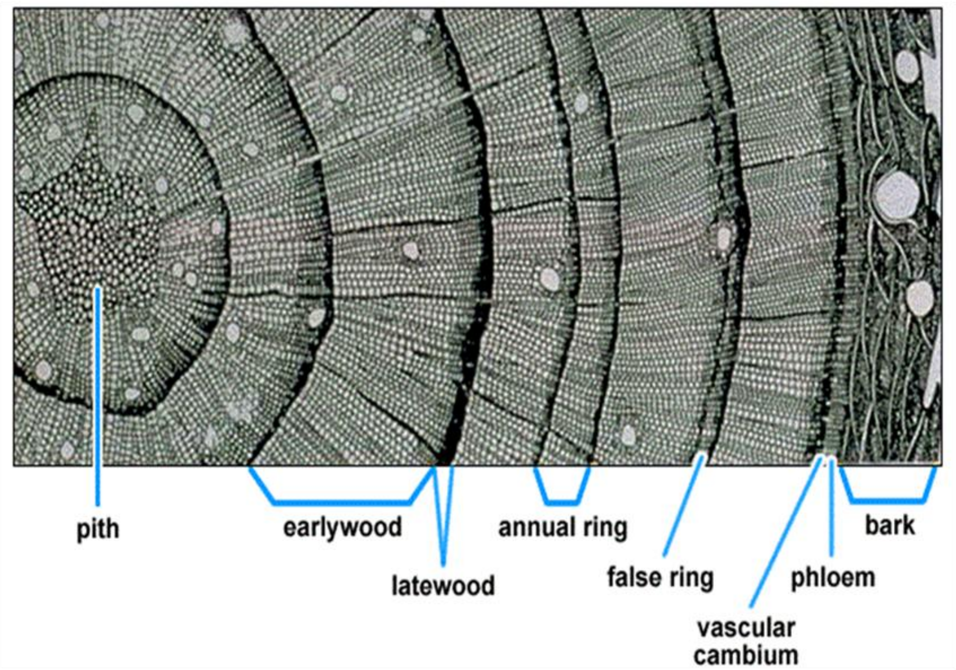

Fig 1 Cross-section view of tree rings of *conifer* wood [3]

- Pre-processing
- Identification of the pith
- Profiles generation

As per literature if an automatic system is developed in this area; this will eliminate the complex task of human for tree ring analysis.

Major factors affecting tree rings thickness:

- Climate
- Physiological aging processes
- Disturbance factors
- Outside or within the forest

Majority of the techniques works accurately for *conifer* wood when the ring boundaries are properly defined. But all the techniques fail when tested on wood type i.e. *ring-porous*.

Different studies are carried out in this area but majority of studies are semi-automatic in nature. Discussion on various types of existing work in this area is presented in Sect. 2. Existing applications are described which utilize different packages in Sect. 3. The system performance mainly depends upon the different parameters such as image acquisition and image filtering. Different parameters affecting the performance of the system is described in Sect. 4. General discussion on different methods applied and gaps are also presented in this area in Sect. 5.

2 Current scenario of computer vision in dendrochronology

An interactive method is proposed to measure the width of tree-ring using a personal computer and a high resolution scanner [4]. Interactive data language environment (IDL 5.0) is used for programming to process the scanned images of tree rings. The enhancement of the ring contrast has been done by the developed program and thus produces ring thickness time series. Resolution of the images is scanned above 900 dots per inch and images are saved in bmp format. By taking initial position at the pith of tree ring of the grey scale image; operation is performed by selecting with the mouse (left key). On every ring, consecutive clicks are made. After recording the position values, width is computed by subtraction of two consecutive tree ring locations. If the rings are overlapping with each other, then high resolution scanner must be used. This method is easy for implementation with low cost. When the tree rings are not overlapped with each other, this technique is best executed.
Another system attempts to automate the work for detection of tree-rings using generalized hough transform [5]. The system works well for noisy images as well as for images having partial rings; this can be observed from the results as system accurately identifies 80% of tree rings which are presented in the database. Then the results of developed system are compared with expert of dendrology. The main parameters required for this purpose are wood center and polygon which indicates the perimeter. The major steps are filtering of the rings, accumulation, and the selection of rings. The steps followed are also illustrated in Fig. 2. The ring center is obtained automatically but for perimeter system asks from the user. The processing time for one wood disc is 172s. Majority of the time is spent in accumulation; however the less time is spent in reading and transformation stage.
In dendrochronology, for image acquisition a new system is developed known as ATRICS [6]. System is compared with existing techniques such as flatbed scanners. System provides much higher details than the existing systems due to numerous advantages of optical magnification. System provides quite acceptable results such as no tree rings are missing due to stitching process. The system also works well for long cores and possesses no problem.
Usage of computer vision with image processing techniques in wood working industry is described in the study [7]. Manual work in this industry can be removed by automated systems utilizing the concepts of vision. For accessing the timber quality i.e. wood defects are checked using different techniques such as SOM self organizing map. The system provides the 91.17% classification accuracy.

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Method based upon detection of gradient peak of the image and linking is proposed for analysis of tree rings [8]. The system is fully automatic and involves image processing techniques to detect boundaries of tree-ring. The system easily works on different types of wood and tree species. The system is tested on wood cores of different 12 species. The system provides the 100% accuracy for detecting the boundaries of tree rings for *conifer* variety. For diffuse-porous variety, the results are not accurate but still acceptable. The main objective of the system is to automate dendrochronological calculations.
Active contours which are mainly used in medical images are combined with image filter based on Sobel operator for detection of tree rings [9]. Main focus of the system is to remove irregularities produced by colourisations, cracks, or branches. The system is tested on different species. The system is semi-automatic in nature. The system is tested on different conifer species.
Dual tree complex wavelet transform concept is utilized for proposing an automatic system to identify tree rings [10]. The system does not require any localization of the pith. The system is tested on *Abies alba* wood which have age 10 to 50 years. The system provides F-score of 0.91 for the delineation quality. Another study detects the tree ring and measure distance among the ring boundaries [11]. Sample is obtained using grinder followed by click of high resolution image. The system takes less time when low resolution image is processed but the system does not give appropriate result for ring detection. System works for both the types of

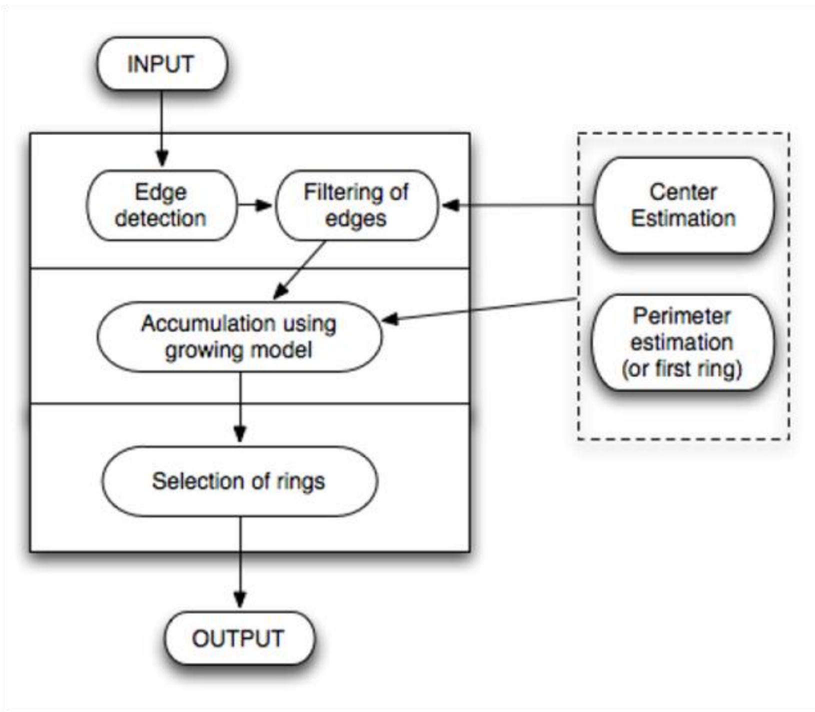

Fig 2 General steps followed in tree rings analysis[5]

images i.e. color as well as black and white images. Canny edge technique is used to detect the boundaries of ring. Then the radius value is calculated from pith of tree to the ring boundary. Then the results are stored in excel sheet. For validation purpose, samples of *Pinus roxburghii* are taken. Then high resolution images of these samples are taken. The software detected 10 and 24/25 tree rings in different samples. For validation purpose the results are cross-checked from the domain expert. Expert detected 11 and 28 rings in respective samples. Between the computed and experts results, the error percentages reported are 9.09 and 14.28. The system provides the accurate results for the samples when the rings are not close to each other.

Autoflourescence technique is used for enhancement of images of the tree ring [12]. To check the efficiency of the system; different techniques are compared such as green fluorescent protein filter, UV filter, red fluorescent protein filter, and natural light. This technique is tested on 38 species of tree with various boundaries of the growth-ring. Results are dependable on the species sample. Flouroscence may be useful when scientists face difficulty during counting of tree-ring. It may also assist to recognize new species suitable for tree-ring studies.

An improved tree-ring dating method able to identify and count tree-ring boundaries from images of wood cross sections is proposed [13]. It can also be utilized to study tree-ring features in future research. Hue saturation intensity (HSI) color is used to remove blue background to get area of interest. Watershed and the window method are used to segment heartwood and sapwood area. Then the total number of rings is counted. A pilot learning is performed using online library of seven images and *Pinus massoniana* wood five scanned images of discs given by Zhejiang A&F University. When some color difference between sapwood and heartwood is present; then this system can be used for identification of tree rings.

3 Existing Applications

MtreeRing

Precise calculations of ring-width are required for dendrochronological study. *MtreeRing* R package is used for ring-width calculations from scanned images of sample. For noise reduction sequential filter is mainly used [14]. By steepest negative slopes ring boundaries are identified. The package gives three different methods such as canny edge detection, watershed segmentation, and linear identification algorithm. Each method has its own advantages and disadvantages. In case complex background, the user can manually put mark on tree rings of different species. After the results obtained from the system, the results are compared with WinDENDRO for coniferous species. There is no significance difference among MtreeRING and WinDENDRO. The user developed R-based application by utilizing the Shiny framework. The system has drawback i.e. system is semi-automatic in nature. The

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Fig 3 Scanners utilized in WinDENDRO for tree ring analysis [18]

advantage of system is that user do not requires any experience in programming. User can run the system on their local system or on remote server.

SigmaScan

Another semi-automatic system uses *SigmaScan*, in this one parameter gives the width of ring marked by user on the images [15] and stores the data in excel. The system provides pith distance and also provides inter-series correlations. Another parameter identifies the latewood-earlywood by measuring darkness across a specific path. Third parameter provides the automatic detection of boundaries. The system development is done in Visual Basic; the system also uses existing programs.

DeepDendro

Information conveyed by tree rings gives details regarding change in environmental conditions. For analysis of tree rings, boundaries need to be identified [16]. Earlier this is done manually using a moving table, stereoscope, and data recorder. This process require large amount of time when dealing with extensive tree-ring series. Various studies are carried out in this area. But mainly all studies utilize computer vision techniques. Accuracy is less and all the work mainly concentrates on conifer wood. But the recent studies failed when tested on ring-porous wood type.

In recent study DeepDendro method is developed which involves automatic detection of tree rings using convolutional network. As per the literature survey this is the first attempts by author which uses ConvNets to detect tree rings. The proposed approach is tested on three different species dataset images. The tested dataset have more than 2500 tree ring boundaries. System provides quite acceptable results i.e. 96% accuracy. Only small numbers of boundaries are introduced with the DeepDendro method. The system generates results without the intervention of the user.

measuRing

In R environment, measuRing package measures the ring width using statistical methods [17]. From the scanned images, ring borders are identified using R statistical analyzes. First

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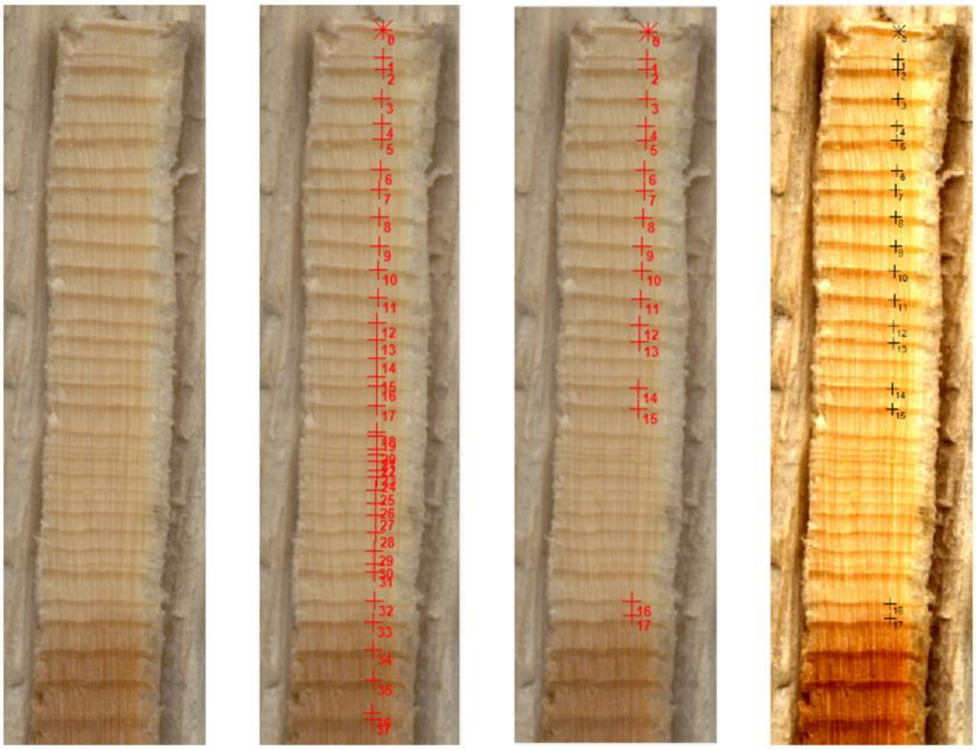
Vol-22-Issue-16-August-2019



(a) original image (b) manual - original image (c) automatic - original image (d) automatic - normalized image

Fig 4 Tree ring detection results [19]

the image is processed and then luminance is computed that gives a gray level matrix. The package provides the functionality for visually include or exclude the borders of ring on R graphical device. The system automatically detects ring borders using linear identification method. Based upon the negative extreme values, the method detects ring borders.

WinDendro

For dendrometrists and dendrochronologists, WinDENDRO has been specially designed for an accurate and competent way to calculate annual tree-ring widths and also measure other parameters (maximum, minimum, and average density value, width of earlywood and more) [18]. WinDENDRO can examine tree-rings from the wood disks, X-ray films, cores, and images generated by film less digital X-ray structure. The scanners used for the tree ring analysis are shown in Fig. 3. WinDENDRO gives entire system or software only. The software is available in different versions with different costs and functionality. The system is regularly updated every year based upon the technological advancements.

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Vol-22-Issue-16-August-2019

4 Challenges

As per literature the images are taken from the cross-section of the species. However this method is destructive in nature. But the result of the system mainly depends on the resolution of images. So, high resolution images are required for analysis of tree ring. In case of low resolution images, the close rings are not detected. During pre-processing phase if the horizontal intra-ring connections are present then erroneous results may occur. Also the noise level present in image also affects the output results. In recent study different pre-processing and feature extraction methods are tested. The results are illustrated in Table 1. Although system detects 37 tree rings when round norm, SDA method is applied. But the system detects only 34 rings correctly. Still the 100% accuracy is not achieved by testing different image processing techniques. The results of the system are shown in Fig. 4. In case of automatic system, 45.9% accuracy is achieved.
It can be easily observed that none of image processing techniques work efficiently. For the best case, the outcomes still need to be improved as some tree rings are falsely added or missing. Therefore, a dedicated computer vision system is required which mainly emphasizes on identification of existing rings and avoid recognition of non-existing rings.

5 Conclusion and Future Scope

Image processing techniques are broadly used in forestry domain to automatically identify the tree rings and also provide tree ring width. Researcher's main aim is to reduce the amount of

Table 1 Tree ring analysis using various image processing algorithms [19]

method	manual	automatic	normalized	global thresholding	local thresholding, S, m	local thresholding, S, i	local thresholding, V, m	contrast equalization	CLAHE, slope 3	CLAHE, slope 5	CLAHE, slope 7	Haralick, average	Haralick, cluster tendency	Haralick, energy	Haralick, entropy	Haralick, intertia	Haralick, skewnes	Haralick, variance	directional	SDA	Round Norm, SDA
detected	37	17	17	23	29	31	31	17	21	24	25	4	16	33	30	13	28	14	30	32	37
correct	37	16	16	23	29	30	31	16	21	23	24	3	15	27	25	11	19	13	30	32	34
poor accuracy	0	0	2	3	2	1	0	0	0	0	0	3	0	1	1	0	8	0	1	0	0
incorrect	0	1	1	0	0	1	0	1	0	1	1	1	1	7	5	2	9	1	0	0	3
missing	0	21	21	14	8	7	6	21	16	14	13	34	22	10	12	26	18	24	7	5	3

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labor work in identification of tree ring. Obviously, an enormous range of applications are available in the literature with supportive facts. The reported detection accuracy values additional confirm the scope of these techniques in tree ring analysis area.

Grouping of new imaging acquirement and high-speed techniques give new research directions to put up enhanced techniques for improvements in forestry domain. However different computational models are presented for analyzing the various trees ring patterns. But still there is not a competent model which provides 100% accuracy for detection of tree rings. However some attempts have been made to make system automatic but majority of system are semi-automatic and requires user intervention. But still the methods require some improvement for enhanced performance.

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