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Towards automatic tree rings detection in images of scanned wood samples

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ABSTRACT

In this paper, the problem of automation of dendrochronological measurements is considered. In particular, a fully automatic, image-based approach for detecting tree-ring boundaries in wood core images is introduced. The method is based on image gradient peak detection and linking. Unlike other existing approaches, the proposed method performs well on a variety of wood types and corresponding tree species. The results of applying the proposed approach to scanned images of wood cores representing 12 tree species (4 conifer and 8 angiosperm) are presented and discussed. Analysis of the results shows that the method performs almost faultlessly for conifer species, detecting almost 100% of tree-ring boundaries. In the case of diffuse-porous species, the results are not quite as good, but still at a level of 85% of properly detected tree-ring boundaries. For ring-porous species, the method has some problems, which are described in the paper.

1. Introduction

Tree-ring analysis is a method widely used in many different fields of science, e.g. archaeology (Čufar et al., 2015; Danek et al., 2007), paleoclimatology (Barniak et al., 2014), climatology (Meko et al., 2011; Koprowski, 2013; Trindade et al., 2011; Danek, 2009), ecology (Filibeck et al., 2015), geomorphology (Wistuba et al., 2015), environmental studies (Barniak and Krąpiec, 2016; Danek et al., 2015) and many others. It is based on information contained in the annual wood increments of trees (tree rings). Of the features of annual increments that are used in tree-ring analysis, the most popular is width, which is a distance measured between two consecutive tree-ring boundaries.

Traditionally, the detection of tree-ring boundaries and measurement of the width of particular rings is mostly performed by a trained operator with an experienced eye using dedicated equipment composed of a stereoscope, moving table and a data recorder. This is the most popular method of measurement as it is the most accurate and reliable; however, it is also cumbersome and time-consuming, since the tree rings have to be measured manually one-by-one. This limits its applicability, especially in the case of long tree-ring series.

Alternatively, tree rings can be detected and measured from scans or photographs of wood samples using dedicated programs (e.g. WinDENDRO™, CDendro & CooRecorder, LignoVision™). This solution has recently become increasingly popular since automation can greatly speed up analysis when compared to classical measurement using dedicated equipment. However, the applicability of image-based tree-ring measurements is still limited due to accuracy and reliability issues, or its dependency on many factors such as sample preparation, image resolution or wood type. Therefore, the existing software often fails to detect tree-ring boundaries, even when they are easily distinguishable for an expert.

Developing fully automatic and universal solutions for image-based tree-ring detection is an extremely difficult task. Although three main groups of wood (conifer, ring-porous and diffuse-porous) that are considerably different in anatomical structure can be distinguished, the structure of tree rings can sometimes greatly vary between tree species of the same group. Moreover, differences can sometimes be observed between tree rings representing one tree species (depending on the environment in which the tree grew), or even in one specimen. All these differences translate into a variety of characteristics of wood images (Pan and Kudo,

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2011). Therefore, although universal solutions appropriate for all tree species are desired, most approaches reported in the literature concern only one tree species (Wang et al., 2010; Borianne et al., 2011; Entacher et al., 2007; Cerda et al., 2007; Norell, 2011; Rigozo et al., 2004). To the best of our knowledge, there is only one work which collectively addresses a few species (von Arx and Dietz, 2005). Nevertheless, all of the existing automated tree-ring detection solutions are far from being reliable enough for use on the anatomical structure of most types of wood.

Bearing in mind the aforementioned factors, the approach proposed in this paper is a step towards introducing reliable automatic measurements of tree rings into dendrochronological practice. In particular, this approach fully automatically detects and delineates tree-ring boundaries in scanned images of wood cores. Unlike other approaches, the application of the proposed method is not limited only to one anatomical wood type.

The following part of this paper is structured as follows. Firstly, in Section 2 existing approaches for image-based tree-ring detection are briefly reviewed. This is followed in Section 3 by a detailed description of the proposed approach. Section 4 describes the dataset of wood core images used in this study. The results of the proposed approach are presented and discussed in Section 5. Finally, Section 6 concludes the paper.

2. State of the art

Although research on tree rings is long-running and well-established, methods which enable fully automatic and reliable detection of tree rings are yet to be developed (Laggoune and Guesdon, 2005; Sundari and Kumar, 2014). There are some approaches which can semi-automatically detect tree rings in images of wood samples (e.g. Lara et al., 2015); however, their applicability is limited to one wood type and they require input images with certain characteristics. Additionally, a user must interact with the image which may be cumbersome in the case of many tree rings and big datasets.

The variety of existing tree-ring structure types has resulted in a multiplicity of tree-ring detection solutions which differ both in the method of image acquisition and approaches to consecutive stages of image processing. These are briefly outlined below.

2.1. Image acquisition

The first step in the tree-ring detection procedure is image acquisition (Spiecker et al., 2000). Images of trunk cross-sections or wooden cores are most popular in tree-ring image processing studies (Kennel et al., 2015; Henke and Sloboda, 2014; Lara et al., 2015; Helama et al., 2016). Images of wood obtained with X-Rays (e.g. densitometry, tomography) are also used (Polge, 1970; Schweingruber et al., 1978; Borianne et al., 2011; Entacher et al., 2007). For the wood cores considered in this paper, the most common approach is the use of a microscope with a digital camera (Helama et al., 2016; Giantomasi et al., 2009; von Arx and Dietz, 2005). However, alternative approaches have also been proposed. For example, Sioma and Socha proposed a system of tree-ring measurement based on a CCD camera with a resolution of 0.016 mm/pixel (window size of 640×480) (Sioma and Socha, 2016). The very popular method proposed in Latte et al. (2015), Laggoune and Guesdon (2005), and Rigozo et al. (2004) uses a scanner to obtain images of wood cores; the advantage of this approach is elimination of the parallax phenomenon error. However, using standard devices limits the resolution of the obtained images (usually up to 1800 dpi), which may cause deterioration of image information of some narrow tree rings, which can subsequently be missed by a tree-ring detection algorithm. An extraordinary acquisition technique reported by Wagner et al. (2011) was laser scanning with a Faro ScanArm laser; however, this kind of approach is of limited use since it requires sophisticated equipment.

2.2. Preprocessing

In the existing approaches to tree-ring detection, the image acquisition step is followed by image preprocessing which normalizes and standardizes input images in order to ensure uniform processing and enhance images by removing noise or redundant information. The preprocessing approach applied strongly depends on the image acquisition technique and the resulting image type. In the case of grayscale images, less preprocessing is required and the resulting image size is smaller. Therefore, some authors (e.g. Laggoune and Guesdon, 2005; Rigozo et al., 2004) use images obtained directly in grayscale using digital photography or scanning. However, this solution causes significant information loss because the blue channel sometimes contains important information (Campbell et al., 2007; Rydval et al., 2014). Therefore, most of the reported studies utilize color images. In such cases, some authors propose color normalization in order to make tree-ring detection more feasible across all considered wood samples. In the case of RGB images, this involves simple color channel averaging with weighted intensity of the green channel (Lara et al., 2015), or weighting the different color channels according to their importance for optimal image contrast (von Arx and Dietz, 2005). More advanced approaches include color space transformation. For example, Cerda et al. (2007) applied a transformation to HSV color space and then processed the saturation channel since it best fitted the examined data (radiata pine wood samples).

Another issue considered in the preprocessing step is noise removal. For this purpose, in Rigozo et al. (2004) the authors applied some custom software which allows hand correction of brightness and smoothing. However, this kind of processing strongly relies on a personal assessment of image quality and may provide results which vary depending on the user. In Lara et al. (2015) low frequencies were subtracted to normalize image luminance. Another popular method of noise removal is Gaussian filtering, which was used in the example in Entacher et al. (2007). An alternative approach proposed in Wang et al. (2010) involved the application of morphological processing to reduce cells which could be considered as noise.

2.3. Tree-ring detection

Since tree-ring boundaries manifest themselves as edges, the most important step of wood image processing is associated with edge detection. Most tree-ring detection approaches use classical (image first derivative based) filters for this purpose, such as Sobel (Henke and Sloboda, 2014; Borianne et al., 2011), or the more advanced Canny algorithm (Cerda et al., 2007; Conner et al., 1998). A comprehensive comparison of Sobel, Prewitt, Roberts and Canny edge detectors was presented in Sundari and Kumar (2014), in which the Sobel filter was finally chosen (Sundari and Kumar, 2014) as the best one. Other authors (Entacher et al., 2007) have applied the Mexican hat operator (a discrete approximation of an inverted Laplacian of Gaussian operator based on second image derivative). However, all the aforementioned edge detectors are sensitive to noise; thus, they often produce false rings when applied directly to images of wood samples. This occurs especially in the case of tree species with barely visible tree rings. Therefore, other more sophisticated approaches are also used in tree-ring analysis. For example, in Wang et al. (2010) Linear Expansion Processing (LEP) was used to obtain the exact number of tree-ring boundaries. In the LEP approach, the number of pixels of a given brightness in the vector of pixels is firstly counted. Then, if