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Wood species recognition through multidimensional texture analysis

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ABSTRACT

Wood recognition is a crucial task for wood sciences and industries, since it leads to the identification of the anatomical features and physical properties of wood. Traditionally, the recognition process relies almost exclusively on human experts, who are based on various characteristics of wood, such as color, structure and texture. However, there are numerous types of wood species in the nature that are difficult to be identified even by experienced scientists. Towards this end, in this paper we propose a novel approach for automated wood species recognition through multidimensional texture analysis. By taking advantage of the fact that static wood images contain periodic spatially-evolving characteristics, we introduce a new spatial descriptor considering each wood image as a collection of multidimensional signals. More specifically, the proposed methodology enables the representation of wood images as concatenated histograms of higher order linear dynamical systems produced by vertical and horizontal image patches. The final classification of images, i.e., histogram representations, into wood species, is performed using a Support Vector Machines (SVM) classifier. For the evaluation of the proposed method, a dataset, namely "WOOD-AUTH", consisting of more than 4200 wood images (from cross, radial and tangential sections of normal wood structure) of twelve common wood species existing in Greek territory, was created. Experimental results presented in this paper show the great potential of the proposed methodology, which, despite a small number of misclassification cases with regards to both anatomically similar and different species, outperforms a number of state of the art approaches, yielding a classification rate of 91.47% in wood cross sections.

1. Introduction

Numerous wood species with various anatomical characteristics and physical properties are used in industry for the manufacture of a wide range of products. Depending on their properties, different wood species have different usage and, as a consequence, there is a great variation in their price. The identification of wood species is a critical process, which not only leads to the proper utilization of woods, but also to the prevention of wood smuggling, as well as to the protection of several endangered tree species. Therefore, wood materials need to be examined thoroughly before their usage in industry, while their import into any country is prohibited without verification and species identification, due to the risk of carrying and transferring harmful microorganisms that can threaten some native species (Voulgaridis et al., 2000).

The recognition of wood species is a laborious process, which is performed by experts, who attempt to distinguish the different species based on their macroscopic and microscopic characteristics. Most of these characteristics can be observed in the transverse or cross section of woods, which is the plane perpendicular to the long axis of the trunk. The next most important surface for wood species recognition is the tangential section, which is the plane parallel to the long axis and tangent to the growth rings, while significant information can also be acquired by the radial section of wood, i.e., the vertical plane from the pith towards the bark (Bond and Hamner, 2002; Jones, 2016). Traditionally, experts use 10-power hand lens or magnifying glass to look the section that is being examined, while additional analysis of the physical characteristics of wood, such as the color, weight, smell and grain pattern can also help experts identify the correct species (Voulgaridis et al., 2000). Since no two pieces of wood, even of the same species, look exactly alike (Conners, 2011), wood species recognition is a difficult task, which is performed only by experienced specialists. For this reason, the needs of reducing the cost and time required for the training of experts and at the same time enhancing the accuracy of recognition

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has significantly increased the research interest on automatic wood species recognition methods.

Based on the recent advances in the area of computer vision and pattern recognition, most researchers have proposed image-based approaches attempting to address the problem either in microscopic or macroscopic scale. In the case of microscopic image analysis researchers aim to identify various microscopic wood features using CCD microscopes and use them as input to the classification system. More specifically, Yuliastuti and Suprijanto (2013) used CCD microscope with 50× magnification and extracted a number of wood features by applying multichannel Gabor filter on the wood pores and concentric curves. Subsequently, an artificial neural network with back propagation method of multilayer perceptron (MLP) was used for the classification of 10 species of wood. On the other hand, Cavalin et al. (2013) proposed a method based on image segmentation and multiple feature sets for the identification of 112 species in a database containing microscopic images. Moreover, Gurau et al. (2013), captured microscopic images of 40×, 100× and 200× magnification and proposed an approach based on ImageJ, an image processing tool that was used for the separation and measurement of anatomical structures of wood sections and the estimation of statistical variables. The accuracy of recognition, however, relies heavily on the correct image segmentation, which remains an elusive goal in computer vision field so far (Wang et al., 2013). More recently Kobayashi et al. (2015) used X-rays for the mapping of woods in images, while other researchers have used spectrum analysis to identify wood species (Puttonen et al., 2010; Rojas et al., 2011). Nevertheless, identification techniques based on spectrum analysis are considered more expensive and they are more suitable to be executed in the laboratory (Zamri et al., 2016).

On the other hand, wood recognition approaches based on macroscopic images have recently attracted increased interest mainly due to their flexibility, simplicity and operability (Hu et al., 2015). To recognize wood species in macroscopic scale, researchers usually employ color analysis (Zhao, 2013) to extract color features, such as wood color variations, or they apply texture analysis aiming to identify various texture patterns corresponding to specific wood species. For the identification of such texture patterns, most of these approaches are based on the use of Gray Level Co-occurrence Matrices (GLCM). More specifically, Tou et al. (2007) proposed a method based on Gabor filters and co-occurrence matrices, while Khalid et al. (2008) extracted GLCM textural features and used an artificial neural network for the classification of wood species. On the other hand, Bremananth et al. (2009) introduced a wood species recognition method based on GLCM and a correlation technique, whereas Mohan et al. (2014) extracted GLCM features, such as entropy, standard deviation and correlation, from image blocks and applied correlation classification for the recognition of wood species. Furthermore, Barmpoutis and Lefakis (2016) used separately three channels of RGB images and GLCM textural features for the identification of wood species. Another forest species recognition method that combines color-based features and GLCM was presented by Paula et al. (2010). The authors composed a database of the Brazilian flora containing 22 different species and used a multilayer perceptron classifier for the identification of species. On the other hand, Prasetiyo et al. (2010) presented a comparative study using several feature extraction methods, such as GLCM, Local Binary Patters, Wavelet transformation, Rankletm Granulometry and Laws' Masks, and various classification techniques. More recently, Samanta et al. (2015) introduced a different approach using Haralick features, which are calculated from the co-occurence matrix, and a multi-layer feed forward neural network trained with fast-back propagation to identify wooden and non-wooden surfaces.

The main limitation, however, of all above approaches is the fact that GLCM is rather sensitive to gray levels, i.e., a wood sample may be misclassified when wood image has different gray level intensity. To address the problem, Hafemann et al. (2014) investigated the usage of deep learning techniques, in particular Convolutional Neural Networks, for texture classification in two forest species datasets, one with macroscopic images and another with microscopic images, while Hu et al. (2015) presented a method based on Scale Invariant Feature Transformation (SIFT) keypoints extracted from wood cross-section images and then used k-means clustering to calculate histograms. More recently, Zamri et al. (2016) introduced a new feature extractor, namely the improved-Basic Gray Level Aura Matrix (i-BGLAM), in order to accurately extract wood features from the wood texture and overcome the limitation of GLCM. In this paper, we propose a novel macroscopic method for wood species recognitions based on multidimensional texture analysis in order to further improve the classification accuracy. Inspired by the dynamic texture analysis techniques applied to video-based flame and smoke detection systems (Barmpoutis et al., 2014; Dimitropoulos et al., 2015; Dimitropoulos et al., 2016), in this paper, we consider each wood image as a collection of multidimensional spatially-evolving signals and we propose a methodology, which enables the representation of wood images as concatenated histograms of higher order linear dynamical systems produced by vertical and horizontal image patches. More specifically, this paper makes the following contributions:

- We propose a novel methodology for the modeling and recognition of wood species. The proposed methodology takes advantage of the fact that static wood images contain periodic spatially-evolving characteristics in each image channel. Towards this end, we introduce a new spatial descriptor by considering each wood image as a collection of multidimensional signals. More specifically, we divide each wood image into a number of horizontal and vertical multidimensional signals and we apply higher order linear dynamical systems analysis in order to extract their dynamics, i.e., the spatial dynamics of vertical and horizontal image patches. Subsequently, we create the vertical and horizontal histogram representations of the image by adopting a bag of systems approach and we concatenate the two histogram representations to form a spatial descriptor for each image. The final classification of images into wood species is performed using a multi-class SVM classifier.
- To evaluate the efficiency of the proposed methodology, we created a dataset, namely "WOOD-AUTH", consisting of more than 4200 images of normal wood structure from cross, radial and tangential sections of the twelve most common wood species existing in Greek territory. The experimental results show that the proposed methodology outperforms a number of state of the art approaches, yielding a classification rate of 91.47% in wood cross-sections images and 84.2% in wood radial and tangential sections.

The remainder of this paper is organized as follows: the next section presents the material used for the creation of the WOOD-AUTH dataset, as well as the proposed methodology for automated wood species recognition. Subsequently, experimental results are discussed, while finally conclusions are drawn in the last section.

2. Material and methods

2.1. Dataset description

In our research we focused mainly on coniferous woods and broadleaf woods, which are widely known as "softwoods" and "hardwoods" respectively, since most species of conifers have moderate or low densities, while those of most hardwoods have moderate, high or extremely high densities. More specifically, we created a dataset, namely "WOOD-AUTH", consisting of samples of normal wood structure of twelve wood species (three softwood species and nine hardwood species) that exist in Greek territory (Table 1). In particular, *Fagus sylvatica's* natural habitat extends over a large part of Europe from southern Sweden to northern Sicily. The distribution of *Juglans regia* (walnut) is widely from the Balkans eastward to the Himalayas and