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Design and prototype development of a computer vision-based lumber production planning system

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Abstract

A computer vision-based lumber production planning system (CVLPPS) is described. Computer axial tomography (CT or CAT) images of hardwood logs are analyzed for identification and classification of internal log defects. Individual CT image slices are analyzed for detection of 2D defects which are correlated across CT image slices in order to establish 3D support and identify true 3D defects. CVLPPS is capable of 3D reconstruction and rendering of the log and its internal defects from the individual CT image slices. It is also capable of simulation and rendering of key machining operations such as sawing and veneering on the 3D reconstructions of the logs. From the 3D reconstruction of the log and knowledge of its internal defects, CVLPPS can formulate sawing strategies to optimize the yield and grade of the resulting lumber. A prototype CVLPPS was developed and tested on CT images of hardwood logs from White Ash, Hard Maple, Red Oak and Black Walnut. Experimental results showed that CVLPPS could identify and localize a large majority of the internal log defects and thereby result in a 23–63% gain in value yield recovery when compared to a lumber processing strategy that did not use internal log structure information. Issues pertaining to the deployment of CVLPPS in a real-time lumber production environment are discussed. It is shown that the various components of CVLPPS are amenable to parallel and distributed computing, thus making a real-time implementation of CVLPPS practically feasible. CVLPPS could also be used as a decision aid for lumber production planning and an interactive training tool for novice sawyers and machinists.

Keywords: Lumber production planning; Automated log inspection; Non-destructive evaluation; Non-destructive quality assessment; Automated lumber grading; Computer tomography

1. Introduction

Internal features of hardwood logs such as knots, cracks, decay and other anomalies of tree growth determine their ultimate value. If these defects were known prior to the sawing of the log, optimized sawing plans could be devised to achieve greater value from the log. Production of lumber is essentially a destructive process. With each cut into the log, new information is divulged on the quality of the wood inside which often suggests a different and better sawing pattern. However, since each step in the sawing process is irreversible, the loss in the value yield has already happened and cannot be subsequently rectified. Hardwood lumber production has traditionally had a low conversion efficiency of about 35% [31]. Improving the lumber value yield from hardwood logs has become important to many sawmill managers as the cost of logs has risen to 80% of total production costs [32]. Existing technologies to increase lumber volume by external log inspection have reached the point where little further progress is expected. Even today's most experienced sawyers cannot glean from an external inspection of the log, knowledge of its internal features and their location to any degree of accuracy. It seems reasonable to assume that future gains in lumber value yield will be possible only by internal log scanning.

A detailed knowledge of the presence, location, and size of internal defects prior to the first cut into the log is estimated to lead to potential gains of about 15–18% in lumber value [47,65]. On a national basis this represents a savings of $2 billion for the US hardwood lumber industry. Hardwood resources continue to be underutilized in many regions of the US [64]. Environmental concerns and the ecological need for maintaining biodiversity in forest ecosystems underscore the need to utilize as many hardwood species for wood products as possible, thereby reducing the harvesting pressures on a few select species. Forest products-based economies are also dependent on getting the

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highest-value wood products from a declining forest resource base. Improving the efficiency in converting low grade logs into high value products would reduce harvesting pressure on select hardwood species. High-value hardwoods such as Hard Maple, Black Walnut, White Ash and Red Oak have the greatest differences in value between the highest and lowest lumber grades. Improving yields of higher grade lumber via identification and localization of internal defects and using this information to determine optimal lumber processing strategies will significantly increase the value of these scarce hardwood resources. In summary, optimized production of lumber from hardwood logs would maximize the resulting value of hardwood lumber, allow better utilization of hardwood logs, reduce unnecessary wastage and thus play a significant role in the conservation of valuable hardwood forest resources in the US and all over the world.

Studies of computer axial tomography (CAT or CT) and magnetic resonance imaging (MRI) (also known as nuclear magnetic resonance (NMR) imaging) for internal log defects [9,14,24,32,48,65] have demonstrated that the CT and MRI technologies available today can be used successfully to image the internal features of logs. CT scanners which are essentially solid state (i.e. with a minimum of moving parts) can scan at rates exceeding 30 slices per second. Thus, the technical feasibility of scanning logs in real time is fast approaching reality. However, the computational methods for analyzing the CT images for internal defects reliably and in real time, and exploiting the knowledge of the internal defects to determine optimal lumber processing strategies remain a challenging and open research topic.

In this paper we describe the design and implementation of a computer vision-based lumber production planning system (CVLPPS). CVLPPS is based on an earlier system computer axial tomography-based system (CATALOG) for the detection and 3D rendering of internal defects in hardwood logs [2–4,18,19]. The capabilities of CATALOG included:

1. detection, classification and localization of important internal defects in hardwood logs such as knots, holes, cracks and moisture pockets,
2. 3D reconstruction and visualization of the hardwood logs and their internal defects from the cross-sectional CT image slices.

CVLPPS enhances and extends CATALOG by incorporating algorithms that exploit the knowledge of the 3D structure and locations of the internal defects and the 3D structure of the hardwood log to determine a set of lumber processing strategies that would optimize the grade and yield of the resulting lumber. CVLPPS is also capable of interactive graphical simulation of typical machining operations such as sawing and veneering on the 3D reconstructed log model. CVLPPS could be used as a decision support system for lumber production planning as well as an interactive training tool for novice sawyers and machinists enabling them to practice various lumber production strategies on the computer using *virtual* logs before working on real logs.

2. Review of related work

CT and MRI represent potentially viable technologies for acquiring cross-sectional images of logs. Although MRI is a more recent innovation, CT technology is rapidly approaching the speed necessary for production use [32]. CT scanners typically measure X-ray absorption which is then correlated with material density [40,48]. CT technology, though traditionally used in biomedical imaging, is currently also available for industrial uses such as testing poles and concrete and holds the most promise for adaptation to sawmills.

MRI (or NMR) has been traditionally used to study the molecular structures of solid-state materials and chemical compounds. Since MRI is sensitive to moisture content, it is particularly well suited for detecting internal features of logs that are characterized by varying moisture content in the underlying wood [8,9,14]. Chang et al. [8] have shown that MRI can identify internal log features such as knots, reaction wood, wetwood, and gum spots. Information about uneven moisture content distribution was shown to be useful in identifying potential drying problems. Coates et al. [14] have shown that the cross-sectional MR images of logs can give useful information on the moisture content of various internal wood features. Using a combination of median filtering, moment-preserving thresholding and region growing with the conditional dilation method, they were able to identify major defects such as knots, scar tissue, cracks and holes and separate them effectively from clearwood. Chang [9] also evaluated the economic feasibility of fast MRI systems in hardwood sawmills. It was shown that once MRI systems could be purchased for less than $1 million, their use in sawmills would become economically feasible [9].

Hodges et al. [32] evaluated the economic potential of CT in hardwood sawmills. For large mills (60×10^3 m^3/yr), investments in CT scanning systems could be profitable even with only moderate increases in lumber value yield (5–10%), whereas for smaller mills (12×10^3 m^3/yr), such investments would become profitable only as increases in lumber value yield approached 30%. Hailey and Swanson [30] evaluated CT and MRI techniques and estimated that the value of solid wood products could increase by up to 15% from the use of imaging techniques to identify internal defects in logs. Funt and Bryant [24] evaluated a computer system that automatically interprets CT images to identify knots, rot, and cracks occurring in logs. It was shown that although CT technology could greatly improve lumber grade and quality, it was critical to reduce algorithm execution times, design larger diameter industrial scanners