AUTOMATION FOR PRIMARY PROCESSING OF HARDWOODS

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SUMMARY

Hardwood sawmills critically need to incorporate automation and computer technology into their operations. Social constraints, forest biology constraints, forest product market changes, and financial necessity are forcing primary processors to boost their productivity and efficiency to higher levels. The locations, extent, and types of defects found in logs and on boards determines how these materials should be processed for maximum value and to maximize mill recovery. However, current sawmill machinery and manual techniques are not able to make full use of defect information. Machine vision systems that can automatically locate, size, and identify defects provide valuable information for subsequent computer-integrated manufacturing operations. Computerized manufacturing can then maximize the value of each piece of wood processed. By combining vision systems with computer-integrated manufacturing software hardwood processors can automate their operations to utilize the hardwood resource completely and efficiently.

Key words: machine vision systems, computer-integrated manufacturing

INTRODUCTION

Hardwood timber is a substantial economic staple in the Eastern U.S. Primary hardwood processors there produce more than 10 billion board feet of sawn hardwoods annually. Most of their facilities are relatively small (< 10 MMBF/year) and are located in rural areas. Therefore, the survival of this industry is important for the economic well-being of many communities.

The manufacture of furniture, cabinets, flooring, millwork, and molding, along with hardwood exports accounts for most of high- and medium-grade hardwood lumber consumption. There are several steps in processing hardwood logs into these final products (Figure 1). Roundwood is transported from the woodlot to the sawmill. Logs are then separated into veneer logs and sawlogs. Veneer logs are shipped to veneer mills where they are sawn into flitches and then sliced to produce veneer. Sawlogs are processed into boards of standard thickness. After kiln drying, boards are sent to a dimension mill where they are processed into furniture/cabinet parts, flooring, or moldings. Final cutting, milling, gluing, staining, and assembly occurs at plants that are dedicated to specific final products.

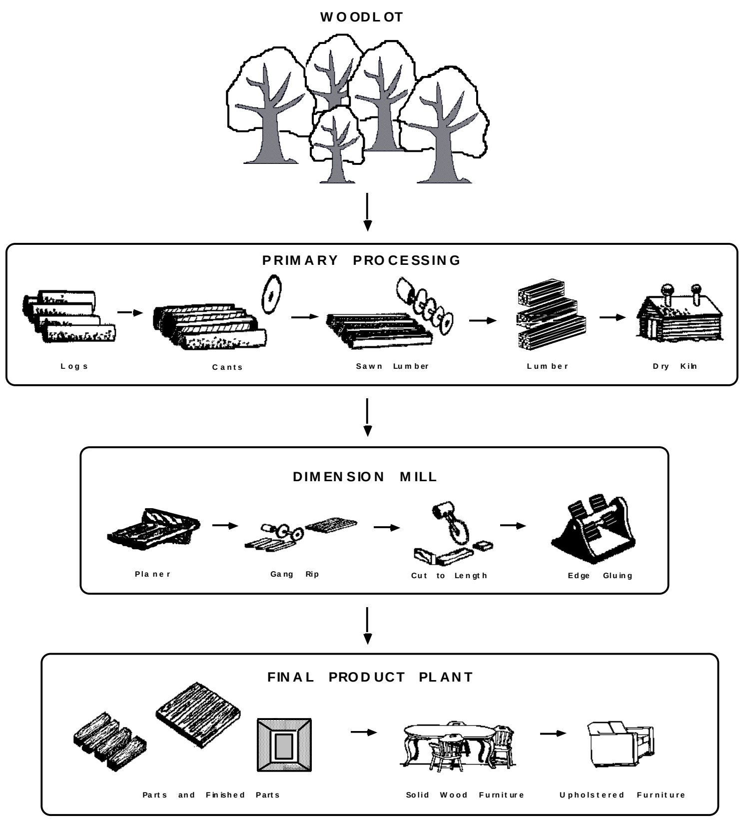

Figure 1. The manufacture of hardwoods into finished products takes place in several different mills. A typical manufacturing scenario is depicted here. The particular manufacturing operations performed at a specific mill are dependent on a company's facilities and the type of finished products made.

Sawmill operators are faced with a number of drastic changes to traditional ways of operating their mills. These changes are precipitated by expanded markets (both export and domestic), low-quality raw material, increased competition from non-wood products, social pressures to manage public lands for nontimber resources, and the reduced profit margin between log costs and lumber prices. There is increased demand for high-quality hardwood lumber and veneer with foreign markets consuming over 5% of the hardwood volume produced in 1987 (Luppold 1991) and accounting for more than 20% of hardwood mill revenues as of 1986 (Araman 1988). More than 60% of hardwood tree volume in Virginia's (U.S.) Northern Mountain region is in tree grade #3 (U.S. Forest Service scale) or below (Johnson 1992). The profit margin between lumber prices and log costs can vary considerably, especially for the select oaks. More socially acceptable alternatives to clearcut harvesting are expected to increase stumpage prices for all species, due to increased harvesting costs per MBF removed. To successfully adapt to these new conditions saw mill operators must: (1) produce high quality and consistent products from current growing stocks of low-grade timber and (2) increase the value of their final products by increasing the value of each board sold or by manufacturing and selling dimension parts rather than lumber.

To squeeze every possible dollar out of each log that a mill processes requires machinery and techniques that eliminate waste, both material waste and processing waste. Such high levels of mill productivity and efficiency can only occur through careful attention to all details of production, from log purchase through to final product. The tight constraints imposed by high productivity goals mean that the sawmill operator cannot depend on highly-trained and motivated workers exclusively. Automation technology is needed to deliver the degree of production control that tight profit margins dictate.

In softwood mills, many computer-based innovations have been introduced, but most of these technologies are too expensive for the majority of small hardwood mills (Skog et al. 1990). Also, many of the technologies developed for the softwood industry do not apply to hardwoods because of differences in end products. Efforts are underway to develop computer technologies that are cost effective and well-adapted to hardwood manufacturing plants. Machine vision systems and computer-integrated manufacturing (CIM) can improve product recovery, increase productivity, improve raw material utilization, reduce costs, improve marketing, and accurately grade lumber.

Because the focus of this paper is primary processing, it is important to outline the different operations performed in a sawmill. Two sawmill operating scenarios are covered: (1) those that produce rough lumber and (2) those that produce cut-to-dimension wood strips that can be used in the production of final hardwood products. Figure 2 illustrates these two mill scenarios. Subsequent discussion of automation techniques refer to these diagrams.

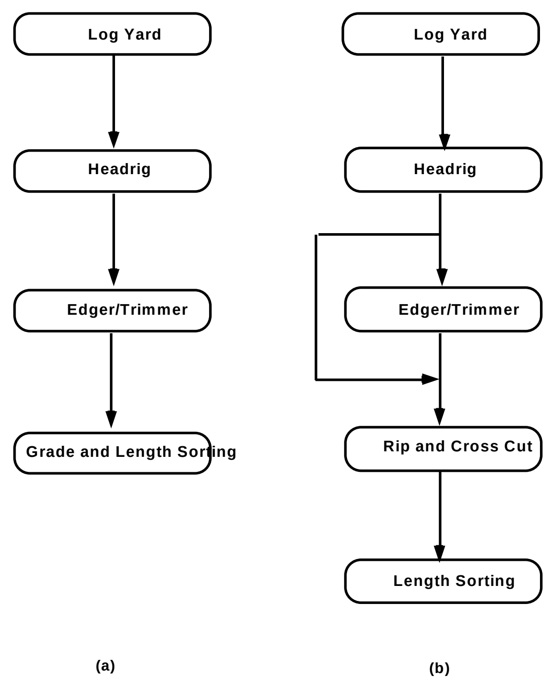

Figure 2. Processing sequences for a traditional hardwood sawmill (a) and log to dimension parts sawmill (b) are depicted. In the second illustration, the board remanufacturing process of the edger/trimmer is optional.

This report outlines current accomplishments in the automation area and projects the uses of still emerging technologies. Two separate stages of mill automation are covered: (1) the collection of information via machine vision systems, and (2) the use of that information for decision making in the manufacturing setting.

VISION SYSTEMS

Machine vision systems are key components of automation efforts in hardwood sawmills. A reliable vision system can deliver information about defect location, size, and type. This is important to make initial processing decisions about a log, as well as to direct the sawing of a log, to grade boards, and to select optimal cut-up for the products produced from a log. Due to the heterogeneity of wood and its interspecific variability, vision systems are the most difficult components of sawmill automation to design and develop. Imaging systems for hardwood lumber (e.g., optical and laser ranging scanning) are less expensive than imaging systems for logs (e.g., CT and NMR), so the former have received the greatest amount of research and development attention.

Vision System Components

A machine vision system includes, in general, subsystems for image scanning, image analysis, and scene analysis. Image scanning uses one or more sensing techniques to measure spatially varying characteristics of an object. For example, optical scanning measures light intensity or color saturation and x-ray scanning measures attenuation of x-rays through a material, which is related to density variation. Whether light intensity or attenuation values or range signals, these analog signals are converted to digital values, stored, and later processed by computer.

Image analysis uses these digital data to display images and to mathematically manipulate images to highlight various characteristics. Areas of homogeneous color or edges between different color areas are examples of useful image features. Often, filtering of the original data can help to eliminate image noise, such as shading caused by uneven lighting. Then, statistical and mathematical techniques are applied to the data to distinguish elements of the image (Ballard and Brown 1982). This process is often referred to as image *segmentation*. Because wood material varies due to the stage of drying and prior handling, image analysis methods must be robust and dynamic.

In scene analysis, "interesting areas" from the segmentation step are aggregated and sized as scene features, and then labeled as particular types of objects. Many recent vision systems employ AI methods to perform scene analysis, including heuristic rules and inexact reasoning , (e.g., Cho et al. 1990). Because segmentation only highlights areas with extreme values, it can be performed independent of species and wood material differences. Recognition of objects in the scene, on the other hand, requires technical knowledge of possible objects to perform domain-specific classification.

Vision Systems for Logs

Determining the location, type, and shape of defects within logs can facilitate automated processing of logs into lumber, rough green parts, or veneer. Defect information can improve three important preprocessing decisions: (1) how to convert tree-length roundwood into logs, (2) whether to process a log into veneer or lumber, (3) how to maximize value yield from a lumber sawlog, and (4) how to orient a veneer log to produce high-quality veneer slices. To do this, the log must be scanned in some manner, the scan information must be interpreted, and a 3-d rendition of the log must be created. Bucking, processing, sawing, or veneer slicing decisions may then be based on this visual rendition of the log .

Tree-length roundwood needs to be bucked into logs in the log yard before further processing into lumber or veneer. If the locations and shapes of internal defects are known, it is possible to cut roundwood into logs while removing major defect areas. This leaves greater areas of valuable clear wood in the remaining log, and gives it higher value. At the same time certain logs can be identified as veneer quality, which would increase log values by a factor of 10 or more.

To scan logs, researchers have investigated a number of nondestructive techniques. These include computed tomography (a.k.a. CT, Funt and Bryant 1987, Zhu et al. 1991), nuclear magnetic resonance (NMR) imaging (Chang et al. 1989), and ultrasonics (Han and Birkeland 1992). The massive nature of log specimens means that each of these scanning technologies requires high power and long scan times, and consequently, are high in cost. Scanners have traditionally been limited by slow scan times; however, recent technological developments have produced ultra fast CT scanners that can create 34 images per second (Roder et al. 1989). Slightly slower scanners (1 image/sec.) are now lower in cost and also mobile. This facilitates the development of a truck-mounted scanner and log handling system that could be moved from location to location.

Most current research efforts are aimed at developing the software to utilize the information collected from scanners. Because the volume of information produced by log scanning is extensive, high-speed computation is essential. Traditional vision system methods (see above) have been applied with some success (Funt and Bryant 1987, Zhu et al. 1991), however, neural network image processing methods are also being tested (Harston and Schumacher 1992). This approach offers the potential of being very fast and also capable of handling the tremendous variety of defect manifestations found in logs. The aim is that as log scanning technology hardware becomes more cost effective (both faster and cheaper), the software tools necessary for vision system implementation will also exist.

Vision Systems for Lumber

There are two distinct situations with respect to automatically detecting defects on lumber, unplaned and planed lumber. Defect detection on *rough* lumber is similar to detection on *surfaced* lumber, but it is much more complex. Surfacing lumber removes many of the visual characteristics of wood that confound the identification of surface features (Conners et al. 1989). Lumber changes in visual appearance as the surface dries. Outside storage and drying can cause color changes due to weathering and ultraviolet light. Handling and storing of wood can introduce dirt onto its surface. The roughness of the wood surface creates shadows that alter visual appearance. Planing boards eliminates most of these problems, but boards in sawmills are processed before surfacing. So, it is important to scan rough rather than surfaced lumber.

There are three categories of defects on lumber. These are: (1) visual surface defects (e.g. knots, holes, splits), (2) board geometry defects (e.g., warp, crook, thickness variation), and (3) internal defects (e.g., honeycomb splits). It is generally recognized that no single sensing modality can distinguish all categories of defects (Szymani and McDonald 1981). The different sensors being applied are: microwaves (King 1978, Portala and Ciccotelli 1990), capacitance sensors (McDonald and Bendtsen 1986, Steele et al. 1991), x-ray imaging (Kenway 1990, Portala and Ciccotelli 1990), laser scanning, and optical scanning (Conners et al. 1990, McMillin et al. 1984). Each of these sensing systems is capable of detecting certain kinds of defects and not others.

Lumber vision systems can be used to remanufacture boards (edging and trimming), to rip and cross cut boards for dimension stock, and to sort lumber by grade and length for market to dimension plants.

Boards coming off the headrig saw can be increased in value by edging and trimming undesirable portions. Regalado et al. (1992) found that the best edging and trimming decisions--that is, producing the highest value boards--are produced by increasing detail of defect information. Although, they found that even minimal amounts of defect information permitted them to obtain 80% of optimum board value. Actual mill worker productivity was much lower than the computergenerated results of Regalado et al., indicating that workers are unable to utilize even minimal board defect information.

It is possible to convert medium- and low-grade logs into end products more effectively by producing green (undried) rough dimension material (blanks) directly from logs. Blanks can be either cut-to-length, random-width dimension stock with defects removed or standard width strips that will be cut to length and have defects removed after drying. Presently, mills process many of these logs into low- and medium-grade lumber or into pallet parts. Blanks may be cut from boards as they come off the headrig or from remanufactured boards (Figure 2). Knowledge of defect location and size is critical to automate the cutting of these parts from boards of varying quality (see below).

Lumber is sold by grade and length. Currently, this sorting process is performed by mill workers who often do not have extensive training in lumber grading. Vision systems can provide the defect information necessary for automated grading systems (see below).

Laser ranging systems are currently the most cost effective scanning method. They provide valuable information about board geometry, and they also detect wane, holes, splits, and some knots. Equipment costs for laser scanning are relative low. The amount of information collected by laser scanning is small enough to process in real time without sophisticated computers. Optical systems, on the other hand provide extensive information about the board surface that allows one to automate other hardwood processing activities, e.g., color matching and grain matching of wood strips. The volume of information collected and the complexity of the vision algorithms make high-speed computers essential for optical scanning. Commensurate increases in computer power and decreases in computer costs that occur regularly, however, make processing speed for optical vision systems a relatively moot concern (Conners et al. 1990). By combining optical scanning with laser scanning to verify wane areas, holes, and splits and with x-ray scanning to verify knots and decay and to detect internal defects, most significant lumber defects can be automatically described.

COMPUTER-INTEGRATED MANUFACTURING

Once information about the hardwood material, either logs or lumber, has been collected by vision systems, it needs to be applied to processing tasks as intelligently as possible. Computer-integrated manufacturing (CIM) systems make processing decisions based on information about log or lumber geometry and on defect size and location. Some of the specific needs in primary processing are decision systems for log sorting, log sawing optimization, lumber grading, and describing potential furniture cuttings in hardwood lumber. The vision systems described above are key to the success of this work.

Manufacturing Systems for Logs

Sorting logs in the yard as veneer or high-quality sawlogs or low-quality sawlogs is currently performed manually. Consequently, visual inspection of logs for geometry and external indicators of defects is the only examination method available. Also, hardwood logs are most often bucked in the woodlot prior to transport to the mill. For these reasons there has been little research effort directed toward determining optimal bucking or sorting of logs based on imaging technology. As scanning systems are introduced they can be implemented outside of the mill proper to help with these important initial decisions.

Even after defects have been located, the choice of a cutting pattern for sawing the log is a complex decision. Many research articles have reported results of different log cutup methods and their impact on the lumber produced (q.v. Harless and others 1991). Some researchers have attempted to visualize the shape of a log and its defects (e.g., Occeña and Tanachoco 1988, Pnevmaticos et al. 1974) using computer graphics. Other have sought to optimize the log sawing process (e.g., Pnevmaticos and Mouland 1978, Occeña 1987, Tsolakides 1969) through some mathematical or logical algorithm. In the first case, the sawyer retains control of the log sawing decision, but is aided by a three-dimensional rendition of the log. In the second case, the sawyer is instructed on how to cut the log to achieve the highest possible value. A third case could also be added in which a sawing method is selected and the sawing operation is completely under computer control.

Several standard sawing methods are available to apply to any particular log. Therefore, it is quite straightforward for a sawing optimization program to simulate each sawing method on a digital image of a log and then select the method that produces the highest log value. This may not, however, result in a true optimal log value because none of the standard sawing methods uses complete defect information. Consequently, there is a need to create a truly optimal sawing method that fully utilizes log defect information. Without such a method the cost effectiveness of advanced log scanning technology relies solely on the ability of the sawyer to translate 3-d log images into better sawing decisions.

Manufacturing Systems for Lumber

After logs have been processed into boards, these boards are processed into salable products, either graded and sorted lumber (Figure 2a) or length-sorted dimension blanks (Figure 2b). This may involve edging and trimming boards, grading boards, or determining potential cuttings based on a cutting bill that specifies blanks of particular sizes. Several computer programs are available to make use of machine vision information on defects and board outlines.

One such program grades hardwood lumber (Klinkhachorn et al. 1989) by the standard rules of the National Hardwood Lumber Association (NHLA). This program utilizes some heuristics, but is largely an algorithmic interpretation of the complex and convoluted NHLA rules. It takes a computer file description of the board outline and its defects as input. It then begins with the highest grade and successively checks each grade until the board satisfies the requirements for a grade. While the grading program is exhaustive and accurate, it can be very slow for some boards and therefore is not useful for real-time applications in its present form. Less exact methods, using extensive heuristics or neural networks, may be better suited to most mill applications. Also, while the Klinkhachorn et al. program is a careful implementation of the NHLA rules, oftentimes each mill or lumber purchaser has their own grading biases that they systematically inject into lumber grading to create "personal" grading rules. Vuorilehto (1991) describes a grading program that accommodates such personal grading rules; it "learns" mill specific grading rules over the course of a training batch of lumber. This learning type of grading program may turn out to be more useful because it fits more naturally into a mill's method of operation and, therefore, does not require a change in a mill's treatment of lumber or customers.

For converting sawmill logs into dimension blanks (Figure 2b), a computer program, CORY (Brunner et al. 1989), determines the potential cuttings in a board. CORY works on boards of any size and on either wane-edged boards or boards with wane removed. Exhaustive examination of all possible solutions is avoided by using heuristics and partial evaluation to eliminate portions of the search space that are unlikely to yield good solutions. The program's execution is very fast which makes it attractive for real-time applications.

Lumber grade for a board can be improved by proper edging and trimming of the board. A third program has been developed to help sawmills properly edge, trim, and grade wane-edged sawmill flitches (Regalado 1991). The grading portion of this program is the Klinkhachorn et al. grading program mentioned above. The edger/trimmer program is currently distributed as a training tool for edger/trimmer operators. In this implementation, a library of boards is included that have already had their optimal edge and trim lines calculated and recorded. A user then calls up a board and graphically places edge and trim lines where he or she thinks the board will have maximum value. They can then compare their board value and edge/trim lines with those of the program. Efforts are now underway to convert this program into real-time production software that can be used to control the saw blades of edger and trimmer machines.

CONCLUSIONS

This paper has stressed the application of machine vision technology to generate defect information and CIM software that can exercise this information in processing decisions. Vision systems are becoming commercially available (e.g., Vuorilehto 1991) and CIM software has been around for several years with more being developed regularly. The seminal contribution of recent technology for automation, however, is the advent of vision systems. They provide for the realization of a total system that will allow sawmill automation to become a reality. The final link to complete automation is, of course, computer control of manufacturing equipment. Computer control technology has existed for some time (e.g., Williston 1985) and, therefore, is largely a final engineering implementation task.

Automating sawmill operations has both difficult and easy aspects. First, the natural variability and complexity of wood causes research and development efforts to be very slow and very expensive. Different species of hardwoods, specimens of differing condition (e.g., moisture content, surfacing), and diverse defect types must all be considered. Secondly, because many of these mills are small, there is a reluctance on their part to invest capital in automation improvements unless the payback is very swift and certain and does not require a major retooling of their operations. Finally, on the positive side, because sawmills presently use very little technology, anything that can be done to automate only a single mill processing task will produce substantial economic benefits for the mill.

LITERATURE CITED

Araman, P. A., 1988: New patterns of world trade in hardwood timber products. Pages 391-401 in Proceedings of the 1988 Annual Agricultural Outlook Conference. US Dept. of Agriculture, Washington DC.

Ballard, D. H. and Brown, C. M., 1982: Computer Vision. Englewood Cliffs NJ: Prentice-Hall.

Brunner, C. C., White, M. S., Lamb, F. M., Schroeder, J. G., 1989: CORY: A computer program for determining dimension stock yields. Forest Products Journal vol. 39, no. 2, pp. 23-24.

Chang, S. J., Olson, J. R., and Wang, P. C., 1989: NMR imaging of internal features in wood. Forest Products Journal vol. 39, no. 1, pp. 43-49.
Cho, T. H., Connors, R. W., and Araman, P. A., 1990: A computer vision system for analyzing images of rough hardwood lumber. Pages 726-728 in Proceedings of the 10th International Conference on Pattern Recognition, June 16-21, 1990, Atlantic City NJ.
Conners, R. W., Cho, T. H., and Araman, P. A., 1989: Automated grading of rough hardwood lumber. Pages XVI-1-15 in Proceedings of the 3rd International Conference on Scanning Technology in Sawmilling, October 5-6, 1989, San Francisco, CA.
Conners, R. W., Cho, T. H., Ng, C. T., and Drayer, T. T., 1990: A multisensor machine vision system for hardwood defect detection. Pages 99-111 in Proceedings of Process Control/Production Management of Wood Products: Technology for the '90s, October 31-November 1, 1990, Georgia Center for Continuing Education, Athens GA.
Funt, B. V. and Bryant, E. C., 1987: Detection of internal log defects by automatic interpretation of computer tonography images. Forest Products Journal vol. 37, no. 1, pp. 56-62.
Han, W. and Birkeland, R., 1992: Ultrasonic scanning of logs. Industrial Metrology vol. 2, no. 3/4, pp. 253-282.
Harless, T. E. G., Wagner, F. G.,. Steele, P. H, Taylor, F. W., Yadama, V., and McMillin, C. W., 1991: Methodology for locating defects within hardwood logs and determining their impact on lumber-value yield. Forest Products Journal vol. 41, no. 4, pp. 25-30.
Harston, C. T. and Schumacher, C., 1992: Multi-spectral image interpretation with neural network system. Pages 47-56 in Proceedings of ASPRS/ACSM/RT 92 vol. 4, Remote Sensing and Data Acquisition. ASPRS, Bethesda MD.
Johnson, T. G., 1992: Forest statistics for the Northern Mountains of Virginia, 1992. Resour. Bull. SE-128. Asheville NC: U.S. Dept. of Agric., Forest Service, Southeastern Forest Experiment Station. 50 pp.
Kenway, D., 1990: Computer-aided lumber grading. Pages 189-206 in Proceeding of the 7th Symposium on Nondestructive Testing of Wood, Washington State University, Pullman WA.
King, R. J., 1978: Micorware electromagnetic nondestrictive testing of wood. Pages 121-134 in Proceedings of the 4th Symposium on Nondestrictive Testing of Wood, Vancouver WA.
Klinkhachorn, P., Franklin, J. P., McMillin, C. W., Conners, R. W., and Huber, H. A., 1988: Automated computer grading of hardwood lumber. Forest Products Journal vol. 38, no. 3, pp. 67-69.
Luppold, W. G., 1991: Hardwood lumber demand in the 1990's. Pages57-63 in Proceedings: Nineteenth Annual Hardwood Symposium of the Hardwood Research Council. MIss. State Univ., Starkville MS.
McDonald, K. A. and Bendtsen, B. A., 1986: Measuring localized slop of grain by electrical capacitance. Forest Products Journal vol. 36, no. 10, pp. 75-78.
McMillin, C. W., Conners, R. W., and Huber, H. A., 1984: ALPS -- A potential new automated lumber processing system. Forest Products Journal vol. 34, no. 1, pp. 13-20.
Occeña, L. G., 1987: A pattern directed inference approach to hardwood log breakdown decision automation. Ph.D. dissertation, Purdue University, West LaFayette IN (unpublished).
Occeña, L. G. and TanachocoJ. M. A., 1988: Computer graphics simulation of hardwood log sawing. Forest Products Journal vol. 38, no. 10, pp. 72-76.
Portala, J. F. and Ciccotelli, J., 1990: NDT techniques for evaluating wood characteristics. Pages 97-124 in Prodeedings of the 7th Symposium on Nondestructive Testing of Wood, Washington State University, Pullman WA.
Pnevmaticos, S. M., Dress, P. E., and Stocker, F. R., 1974: Log and sawing simulation through computer graphics. Forest Products Journal vol. 24, no. 3, pp. 53-55.
Pnevmaticos, S. M. and Mouland, P., 1978: Hardwood sawing simulation techniques. Forest Products Journal vol. 28, no. 4
Regalado, C. C., 1991: Optimization of edging and trimming operations for red oak lumber. M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg VA.
Regalado, C. C., Kline, D. E., and Araman, P. A., 1992: Value of defect information in automated hardwood edger and trimmer systems. Forest Products Journal vol. 42, no. 3, pp. 29-34.

Roder, F. L., Scheinman, E., and Magnuson, P., 1989: High speed CT scanning of logs. in Proceedings of the 3rd Internation Conference of Scanning Technology in Sawmilling, Oct 5-6, 1989, San Francisco CA. Forest Industries / Wood World, San Francisco CA. 10 p.

Skog, K. E., Bradley, D. P, Spelter, H. N., Durbak, I., Ince, P. J., Lange, W. J., Araman, P. A., McKeever, D. B., and Zerbe, J. I., 1990: Opportunities to change timber demand through altered timber utilization. Pages 196-238 in An Analysis of the Timber Situation in the United States: 1989-2040. USDA Dept. of Agric., Forest Service, Rocky Mountatin Forest and Range Experiment Station, Ft. Collins CO, GTR-RM-199.

Szymani, R. and McDonald, K. A., 1981: Defect detection in lumber: state of the art. Forest Products Journal vol. 31, no. 11, pp. 34-44.

Steele, P. H., Neal, S. C., McDonald, K. A., and Cramer, S. M., 1991: The slope-of-grain indicator for defect detection in unplaned hardwood lumber. Forest Products Journal vol. 41, no. 1, pp. 15-20.

Tsolakides, J. A., 1969: A simulation model for log yield study. Forest Products Journal vol. 19, no. 7, pp. 21-26.

Vuorilehto, J., 1991: Electronic grading can produce many benefits. Forest Industries, October 1991, pp. 24-25.

Williston, E. M., 1985: Computer Control Systems for Log Processing and Lumber Manufacturing. San Francisco: Miller Freeman.

Zhu, D., Conners, R. W., Lamb, F. M., Schmoldt, D. L., and Araman, P. A., 1991: A vision system for locating and identifying internal log defects using CT imagery. in Proceedings of the 4th Internation Conference of Scanning Technology in Sawmilling, Oct 28-31, 1991, San Francisco CA. Forest Industries / Wood World, San Francisco CA. 13 p.

Manuscript prepared August 19, 1992.

FDK: 52:971
DK: 57.087.1:630*5:007.52
ISBN: 3-905620-24-3

Statistical Methods, Mathematics and Computers

Proceedings of the Meeting of IUFRO S4.11-00
held at
IUFRO Centennial Meeting

Berlin/Eberswalde
August 30 – September 4,1992

Edited by
Michael Kohl
George Z. Gertner

Published by

Swiss Federal Institute for Forest, Snow and
Landscape Research,
WSL/FNP,
CH – 8903 Birmensdorf, Switzerland

1993