Scanning Hardwood Lumber for Processing and Grading—

What to do Now and Why

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ABSTRACT

A cooperative effort between Virginia Tech, the USDA Forest Service, and the industry has led to the development of a new scanning technology to automatically detect lumber grading features that affect the value of the end product. This effort has resulted in several commercial scanning systems now available through Group Seven Systems and Nova Technologies. These systems include a color sorting system for hardwood edge-glued panel parts and an automatic lumber defect scanning system for hardwood rough mill applications. Current research and development efforts at Virginia Tech are now applying the scanning technology to automatic lumber grading and re-manufacturing. Current efforts are specifically aimed at automatically grading green rough hardwood lumber and grading/upgrading rough dry hardwood lumber. Substantial lumber value can be added with such automated systems through increased grading accuracy, custom grades, and optimum lumber upgrading opportunities.

INTRODUCTION

Hardwood lumber is the primary material from which many high-demand furnishings are made including finished floors, cabinets, furniture, mill work, and other household products. Traditionally, the higher grades of preferred timber species (e.g. oak, cherry, walnut, maple, ash, and yellow poplar) have been used by the wood products industry for many years. Consequently, woodworking equipment and the skills of the workforce in this industry have been designed to process wood raw materials that were relatively free from defects, easy to process, and inexpensive to waste. Recent price increases along with a diminishing supply of high quality timber resources has forced the industry to utilize lower grade material. In response to these changes, the hardwood processing industry is aggressively looking at innovative uses of materials and processes to insure their survival in an increasingly complex and competitive environment.

Through more integrated and more controlled processing systems, there is an enormous potential to increase yields and, more importantly, increase value recovery of hardwood processing operations. Such systems require the development of a technology that can detect critical hardwood lumber grading features and then intelligently act upon the system to control and optimize the process in question. Robust sensing all of these critical features is a difficult challenge. The enormous variability in the appearance of hardwood can cause sensing systems to overlook certain features that are critical and to find features that are not truly present. Even if the condition and species of wood are well controlled, sensing systems can have problems reliably locating and identifying key features that affect its value.

In spite of the challenge of developing scanning technologies for the hardwood processing industry, the speed, cost, and sophistication of sensing technology is now making it possible to develop useful scanning methods that can control hardwood processing systems more intelligently. Commercial systems that employ this technology have been successfully developed. These commercial systems have resulted in increased efficiency, value recovery, and control of hardwood processing operations. This technology is continuing to improve and it is becoming more sophisticated so that a greater number of hardwood features can be reliably detected for different processing applications.

Over the past 10 years, researchers at Virginia Tech have experimented with machine vision technologies for lumber scanning. This work has resulted in a multiple sensor lumber scanning system which integrates information from color cameras, an x-ray sensor, and a laser-ranging system. This work has been a cooperative effort between Virginia Tech, the USDA Forest Service, and the industry to develop robust scanning technologies to automatically detect lumber grading features that affect the value of the end product.

This paper will first introduce Virginia Tech's multiple-sensor lumber scanning system. Second, the current status of R&D efforts using the scanning system will be outlined including successful commercial developments as well as promising new technologies soon to be commercially available. Finally, this report will discuss current efforts which are aimed at automatically grading green rough hardwood lumber and grading/upgrading rough dry hardwood lumber.

MULTIPLE SENSOR LUMBER SCANNING SYSTEM

To automate any forest products processing applications requires a machine vision technology that can automatically detect features in the wood raw material which affect the value of the product being manufactured. There are three main categories into which features on logs and lumber may be classified. These are: 1) visual surface features (e.g. knots, holes, splits, decay, discoloration, slope-of-grain), 2) geometry features (e.g., 3-D shape, warp, wane, thickness variations), and 3) internal features (e.g., internal voids, internal knots, decay). Most of these features are treated as defects in lumber grading and need to be removed in manufacturing processes. However, the severity of how a particular feature impacts grade or value depends on the particular processing application.

It is apparent that an ideal machine vision system that can accurately detect these wood features would incorporate various sensing techniques. A prototype multiple sensor lumber scanning system was developed at Virginia Tech to address a variety of wood processing applications (Conners et. al, 1997). A schematic of this prototype is depicted in Figure 1. This prototype incorporates three different sensing technologies:

- a color-imaging system for locating and identifying surface features and color
- a high-speed laser-based ranging system for detecting cracks, holes, and other variations in the thickness of a board
- an X-ray imaging system for locating and identifying features associated with higher or lower density than clear wood.

The prototype is a fill-scale machine that integrates this sensing array with a materials handling system, an image-processing system, a control computer, and machine vision software. Typical widths, thicknesses, and lengths of lumber can be handled by the prototype. The material handling system is driven by a stepper motor that can achieve speeds of up to 360 linear feet per minute (6 linear feet per second). It can be configured for different types of sawmill operations and handle both green and dry lumber. It was built so that other sensing devices besides the three described, can be added and tested. The system was also designed so that the imaging geometry for the various sensors tested can be tested to determine an optimum setting for a particular lumber scanning application.

Color Imaging System

The color imaging system uses two Pulnix color line-scan cameras, one for each face of the board. Under the present system configuration with a processing speed of 2 linear feet per second and a 13-1/2-inch field of view, the color cameras can produce color images with 64 pixels per inch cross-board resolution and 32 pixels per inch down-board resolution.

Tungsten-halogen incandescent bulbs illuminate the board with the light carried to the board surface through a bundle of fiber-optic cables. The ends of the cables are arrayed so that they shine a line of light across each board surface

Laser-Based Ranging System

The laser-based ranging system, designed and built at Virginia Tech, uses a 16-mW Helium-neon gas laser with a 632.8-nm wavelength. A 24-facet polygon scan mirror, rotating at about 30,000 rpm, sweeps a point of laser light across the board. The image is captured by four EG&G black-and-white 128 X 128 array cameras at the rate of 384 frames per second. Under the present system configuration, the cameras have a resolution of 32 pixels per inch cross-board and 16 pixels per inch down-board. The rotating mirror sweeps the point of laser light across the board surface several times in one video frame, causing the cameras to see a continuous laser line falling across the board

The cameras then capture the displacement of the laser line and variations in its light intensity. A special purpose electronics board correlates this displacement to board thickness, voids, splits, and indentations in the board surface to within l/64th of an inch.

X-Ray Scanning System

The X-ray scanning system is much like those used to scan luggage in airports. The X-ray source's kilovoltage and beam current are both variable, with a maximum kilovoltage of 160 and a maximum beam current of 1 mA. The linear detector array that detects X-ray transmission through a board uses a scintillator and a photodiode to generate each pixel value. With the present system configuration, the x-ray detector can generate images with a cross-board resolution of 32 pixels per inch and a down-board resolution of 16 pixels per inch.

Real-Time Image-Processing System

The prototype's image-processing system is a 200-Mhz Pentium PC with 64 Mbytes of main memory running Windows NT. The image processing system uses the MORRPH board, a modular and reconfigurable hardware processing board developed at Virginia Tech (Drayer et al., 1995a, Drayer et al., 1995b). The MORRPH board collects images from all sensors and performs low-level functions on these images such as shade correction, board boundary detection, and image histogram generation in real-time. The real-time image data is transferred from the MORRPH to computer memory using a high-performance direct memory interface board (also developed at Virginia Tech). Through this hardware configuration, real-time processing of the large amounts of image data (as fast as it is collected) is possible.

The software for the image-processing system was written in Visual C++. The software uses the images data generated by the MORRPH board and performs image segmentation and feature recognition methods (Conners et al., 1997). Figure 2 shows the range image (a), X-ray image (b), and color image (c, shown here as black and white) which are generated by the MORRPH board. To handle the large amounts of image data efficiently, the machine vision software process data in a way that minimizes computational complexity and enhances feature detection capabilities:

1. The laser profile image is first analyzed by the image processing software to find areas of the board that fall above or below an acceptable thickness threshold. For example, the darker region on the upper right edge of laser image (Figure 2 a) represents wane. The dark spot on the bottom part of the board represents a crack in an unsound knot. Those areas that are too thin are then removed from consideration in subsequent analysis.
2. The X-ray image data (Figure 2 b) along with color image (shown as black and white) data (Figure 2 c) are used next to locate large defect regions such knots, voids, and decay. For example, the lighter regions on the upper right edge of the X-ray image (Figure 2 b) is due to wane and the light region on the bottom part of the board shows an unsound knot. These large defect regions are removed from subsequent analysis.
3. Finally, the color image is analyzed for smaller surface feature regions (pin knots, stain, and other features that will not show in the laser and x-ray images). By the time the color image data is analyzed, the larger and unambiguous defect regions have already been eliminated for consideration.

The output of the feature recognition software algorithm produces a table, or digital map, that lists the location and identification of features that occur within the board area. This output is shown as rectangular feature areas in Figure 2 d.

APPLICATIONS

Virginia Tech has worked with the industry to develop two secondary manufacturing applications based on its machine vision prototype. Patent applications have been applied for relating to each of these applications. The first application involves the automatic color sorting of hardwood edge-glued panel parts. This application addresses the growing use of edge-glued panels in the manufacturing of doors, drawer fronts, tabletops, and other similar products. Because light-colored stains are becoming more popular, it is critical that the bare-wood colors of adjoining panel parts match both in terms of color and lightness. Also, manual color sorting of wooden panel parts is labor intensive and difficult. Commercial versions of the color sorting system are currently available through Group Seven Systems in Hudson, North Carolina and NOVA Technologies in Charlotte, North Carolina.

The second application of this technology is an automatic defecting scanner in rough mills where defects are removed with crosscut saws. This application involves utilizing a multiple sensor approach to defect detection. The multiple sensor approach is necessary to achieve robust feature detection and correctly differentiate between the many different feature types that can affect the value of the final product. Accurate and consistent defect detection by people require constant attentiveness. As cutting bill specifications become more complex and dynamic, it is increasingly difficult to use manual defecting systems effectively. For example, it is very difficult for the human to remember that a particular feature is considered a defect for one group of parts but acceptable for another group. Commercial versions of this automatic defecting system are also available through Group Seven Systems and NOVA Technologies.

CURRENT RESEARCH AND DEVELOPMENT EFFORTS

The feature data generated by the multi-sensor lumber scanning system can be used in a variety of other applications. Current research and development activity is in progress to adapt and test the scanning system for hardwood primary processing and lumber grading applications. Creating a scanning technology that is both robust and affordable for hardwood lumber manufacturing and grading applications is a challenge. The different mixture of wood species along with the high variability in the surface condition (moisture content, roughness, stains, and soil marks) of wood makes automatic detection of lumber grading features difficult. An example of this difficulty is illustrated in Figure 3. A multi-sensor scanning approach helps the system better distinguish a true grading defect such as a pin knot from a surface stain such as a saw mark.

To determine how perfect scanning needs to be for hardwood lumber grading Klinkhachorn, et al., 1997 performed a grading study on a sample of red oak lumber. In this sample, they found that 5 percent of the boards would be misgraded if small defects (1/4” x 1/4” defects) were missed 60 percent of the time. They also found that less than one percent of the boards would be misgraded if all knots and holes were incorrectly classified as unsound knots as far as the NHLA grade are concerned.

To demonstrate the feasibility of automatic hardwood lumber grading, the lumber scanning prototype has been adapted to scan full-sized hardwood lumber and output board grading data that is compatible with a NHLA hardwood lumber grading software program (Klinkhachorn, et al., 1988; 1992). With this adaptation, lumber can be scanned and graded to determine the feasibility and accuracy of automatic hardwood lumber grading systems. Current studies include testing which sensing technologies, scanning resolution, and feature recognition algorithms are necessary for robust and accurate lumber grade evaluation. Many different lumber species and lumber conditions (moisture content, rough, surfaced, etc.) are being tested to see how feature detection accuracy is affected.

Other processing applications based on NHLA hardwood lumber grading are also being investigated. One application relates to hardwood edging and trimming optimization (Regalado, et. al., 1992). The same feature data can be used to determine where a board should be edged and trimmed for maximum value and automatically position the edger or trim saws. Another application is to use the scanning system to scan lumber and remanufacture it for the highest dollar value based on the current market prices of the different commercial grades (Klinkachorn et al., 1994) or to sort lumber according to a particular customer preference or specification.

The most recent research and development effort using Virginia Tech's lumber scanning technology is in softwood lumber scanning applications. Feature detection accuracy is excellent for Southern Yellow Pine using the mult-sensor scanning system. The feasibility of automatic softwood lumber grading is currently being evaluated in terms of defect recognition accuracy and processing speed.

CONCLUSION

Research and development such as that done Virginia Tech will continue to improve scanning and optimization technologies and work towards adapting them for more applications. The speed and accuracy of these technologies will continue to improve. Also, more fully integrated systems, from the forest to the final products, will be achieved. Furthermore, more efficient systems will be developed to handle and process the huge amount of information that will come with new scanning technologies. Given these inevitable technological advancements, automatic scanning systems for hardwood lumber grading and processing are coming and will change the way the industry does business.

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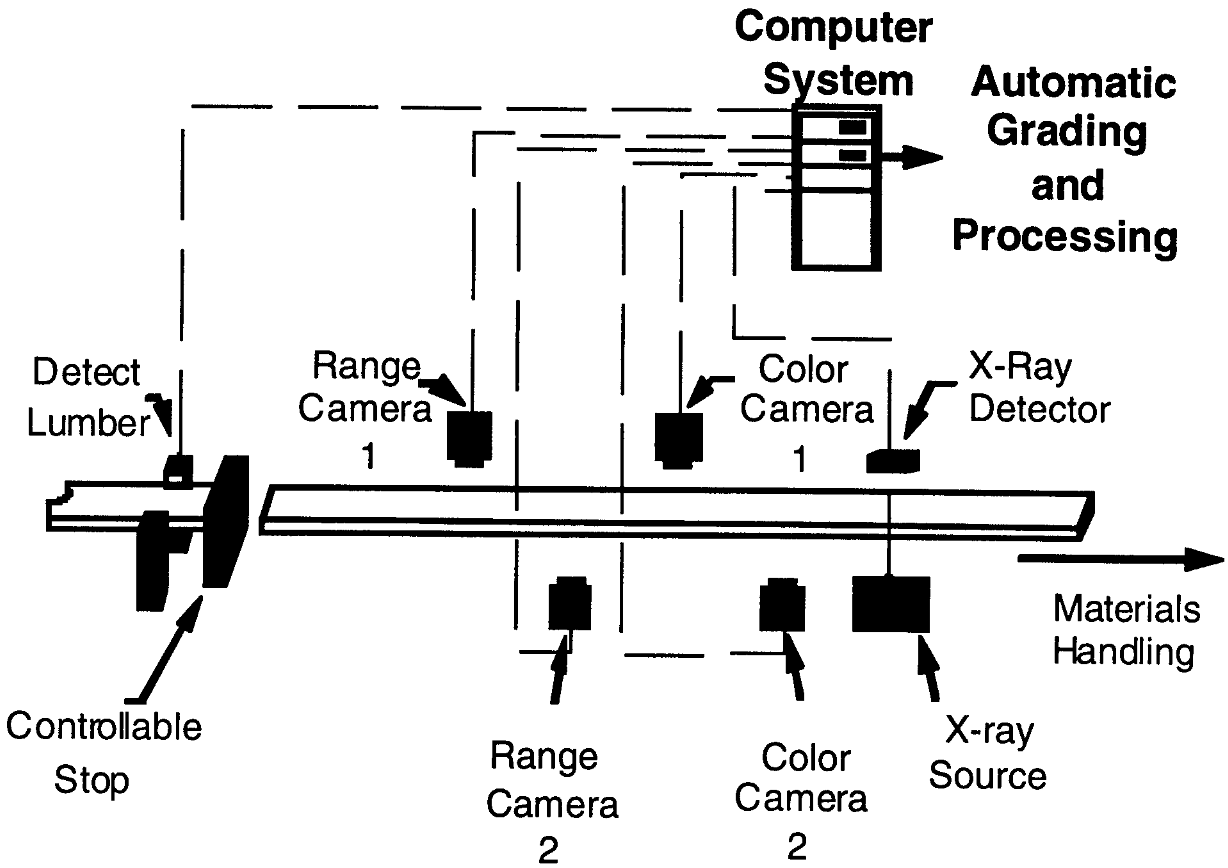
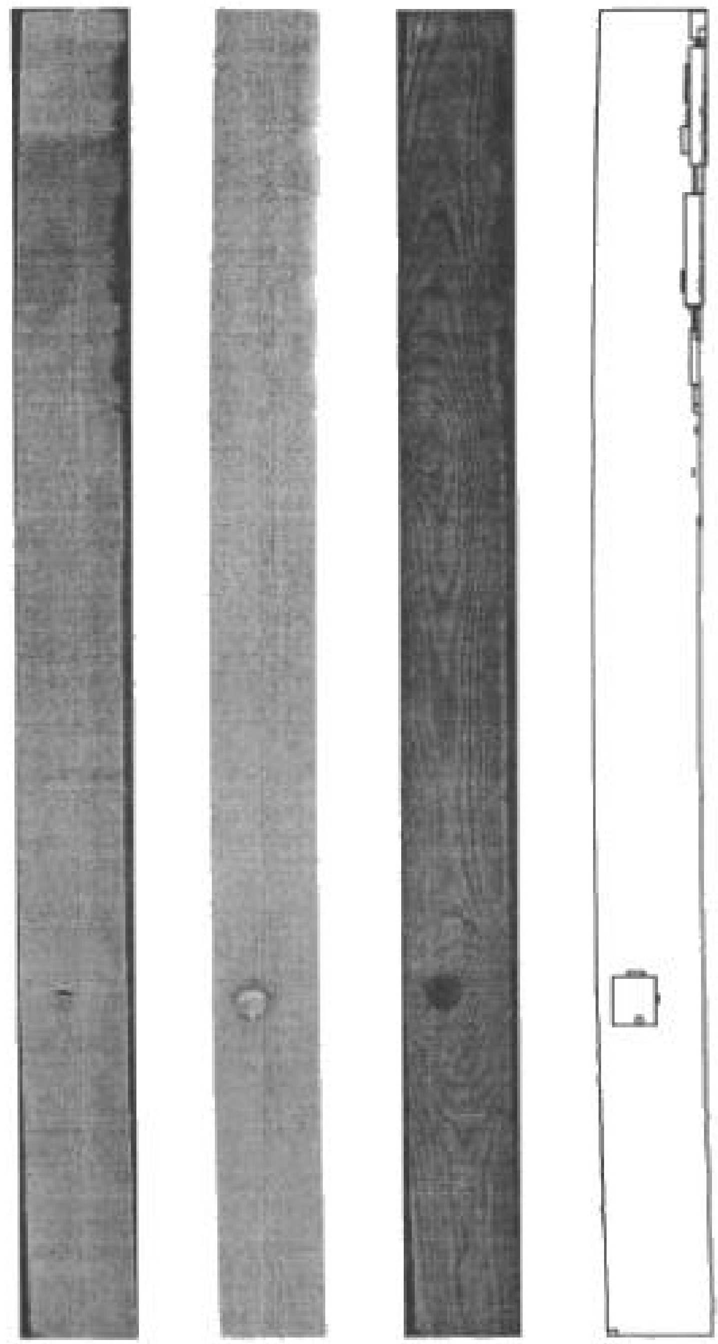


Figure 1. Schematic of the multisensory machine vision prototype for lumber inspection



(a) (b) (c) (d)

Figure 2. Illustration of multisensor machine vision software results on a 5-1/2 inch by 10 feet surfaced red oak board showing the input (a) laser image, (b) X-ray image, (c) black and white image, and (d) resulting defect map with rectangular feature areas identified.

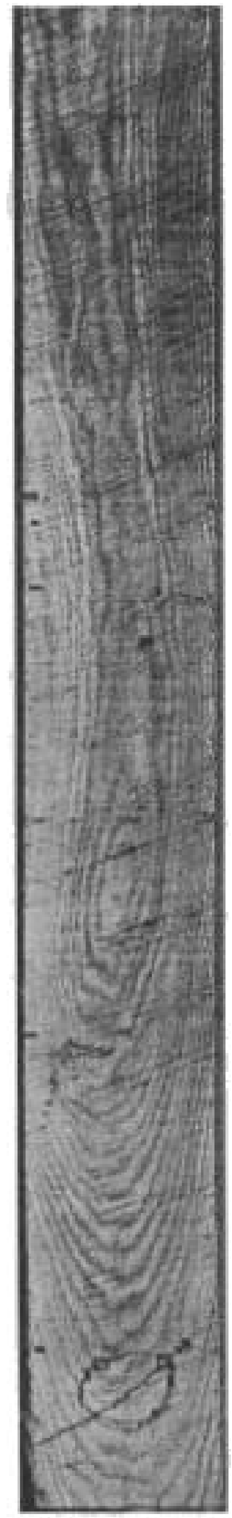


Figure 3. Green rough red oak as shown by this FAS board (8 ft. long by 6-1/2 inch wide) can contain many benign dark marks (e.g. saw marks or crayon marks). These marks can confuse defect detection algorithms that assume darker regions are grading defects. This confusion, as indicated by the black rectangular regions, would result in a 2 Common grade for this face.