A LUMBER GRADING SYSTEM FOR THE FUTURE: AN UPDATE EVALUATION

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INTRODUCTION

Within the next few years, the lumber manufacturing industry will see some of the first installations of automatic lumber grading systems. These grading systems will include complex mechanisms including cameras, lights, lasers, x-rays, computers, electronics and other devices necessary to identify lumber grading features. Sophisticated computer software will be needed to process the volume of information generated by the scanning hardware. The resulting "digital map" of lumber defect data outputted by the software will be used to automatically sort and grade lumber according to standard grading rules (e.g. NHLA hardwood lumber grading rules). However, this data can also provide a potential wealth of information to dramatically reduce costs and increase value recovery by creating a more intelligent, more adaptable manufacturing system.

To automate lumber grading, the industry now recognizes that a multiple sensor approach to scanning must be used to get the required accuracy, consistency and repeatability. There are three main categories into which lumber-grading features 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, compression/tension wood). Most of these features are treated as defects in lumber grading and need to be removed in manufacturing processes.

Recognizing that all grading features cannot be consistently detected with one single sensing mechanism, current R&D efforts are focussing on developing lumber scanning systems that combine 2 or more of these sensing modalities. Many years of industrial experience with some sensors, such as black and white or color cameras, have resulted in fast, robust, and inexpensive sensing systems. Some of the more recently introduced sensing technologies, such as x-rays, microwave and ultrasound, have typically been developed first for an application where speed, cost, and harsh environment are not critical factors (e.g. medical industry). Several years of experience with such sensing systems will be needed before they are reliable and robust enough for lumber manufacturing and grading applications.

Virginia Tech and the Southern Research Station of the USDA Forest Service have jointly developed and refined a multiple-sensor lumber-scanning prototype to demonstrate and test applicable scanning technologies (Conners et al. 1997, Kline et al. 1997, Kline et al. 1998). This R&D effort has led to a patented wood color and grain sorting system (Conners and Lu 1998) and a patented defect detection system for lumber (Conners et al. 1999). The objective of the current study is to test the application of this defect detection system on hardwood lumber grading. We will discuss some of our findings to date and discuss what implications they have in the development of automatic hardwood lumber grading systems.

MATERIALS AND METHODS

Material Selection

Eighty-nine (89) 4/4 red-oak lumber specimens were collected from various mills in the Appalachian region. The lumber was kiln-dried to within 5 to 8 percent moisture content. All boards were at least 10 feet long and 5 inches wide. The boards were re-surfaced with an abrasive planer to remove any surface roughness, stain or soil, and to create a uniform thickness prior to grading evaluation. National Hardwood Lumber Association (NHLA) grades FAS, FAS 1-Face (F1F), #1 Common, #2 Common, and #3A Common were used for the study. The specimen grade mix consisted of 12 FAS boards, 8 F1F boards, 23 #1 Common boards, 20 #2 boards, and 26 #3 Common boards (as graded by mill line graders).

Methods

In testing the accuracy of the multiple-sensor defect detection system, the following hardwood lumber grade evaluations were conducted. Comparisons were made between each of these grade evaluations to develop conclusions about the performance of the automated hardwood lumber grading system and where the system could be improved.

1. *Automated Grade*— the board sample was run through the lumber scanning system to generate laser, x-ray, and color images for each board face. These images were saved for subsequent processing and analysis. Subsequent processing utilized current image processing software developed for Virginia Tech's lumber scanning system (Xiao 2000) to automatically generate a "digital map" of lumber grading defects in a standard format that can be used by grading software. Hardwood lumber grading software, UGRS (Ultimate Grading and Remanufacturing System), was used to grade each board based on the generated digital map (Moody et al. 1998).
2. *Digitized Grade*— The boards were manually digitized for all grading defects. Digitization was done by hand and consisted of mapping out and classifying all of the defects on the board according to the technique prescribed by Anderson et al. (1993). UGRS was used to establish the true grade of the lumber based on the defects identified during manual digitization.
3. *NHLA Grade*— the boards were graded by an NHLA-employed national inspector.
4. *Line Grade*— the original grade of the boards assigned by the line graders at the various mills from which the board samples were collected.

RESULTS

Grade Distribution

Figure 1 shows the grade distribution for each of the grade evaluation methods studied. As expected, there is close agreement between the grade distributions for the *NHLA* and *Digitized* grade methods. Note that the

Digitized grades show less #1 Common grades than the *NHLA* grades. This discrepancy is partly due to extra sensitivity of picking up more defects and slight lumber sidebend or crook in the digitization process. During digitization, there is much more time to consider every possible feature, which can result in a slight bias that is more critical of the board's appearance when compared to the NHLA inspector. Precise and consistent definitions of what constitutes a true grading defect will be key to developing an effective automated lumber grading system. Future efforts will be needed to develop such definitions that can be readily translated into computer code.

The *Line* grade tends to place more boards in the higher grades compared to the NHLA or Digitized grade methods (see Figure 1). Also note that the *Line* grader does not grade any boards as #3B Common. In contrast, the *Automated* grade method tends to place more boards in lower grades. It was observed that some of the *Face and better* boards were downgraded to #1 Common and some #1 Common boards were downgraded to #2. This observation is illustrated in Figure 1 where the *Automated* grading method resulted in the highest frequency of #2 Common boards. A primary cause of this *Automated* grader discrepancy includes falsely detecting defects in the higher-grade lumber. This false defect detection error and implications will be discussed in more detail later.

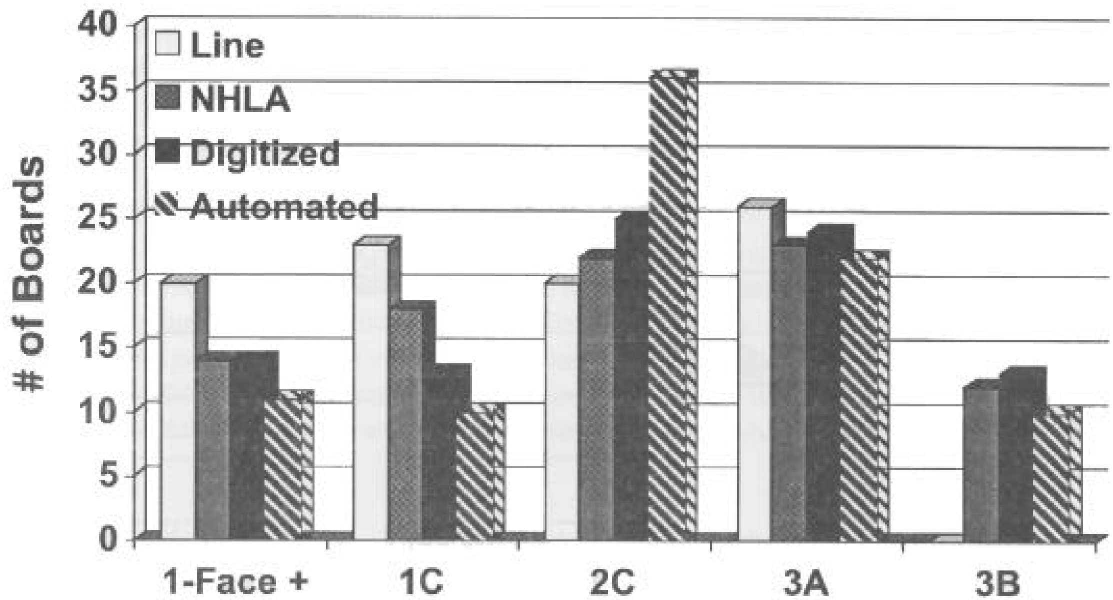

Figure 1. Lumber grade distribution for each of the grade evaluation methods.

Lumber Value

Table 1 shows the value of the 89-board sample based on each of the grade evaluation methods. These values are based on the May 9 Hardwood Market Report (2000). The *Line* grade results in the highest value of $310 for the sample. This value is 20% higher than that estimated by the *NHLA* grader. In terms of lumber value, the *Automated* grade is closer to the *NHLA* grade than the *Line* grade. While the values between the *NHLA* and *Automated* grade methods were within 6% of each other, this difference is greater than the 4% money value allowance that is required by the NHLA grading specification. Even the difference between the *NHLA* and *Digitized* grade methods is slightly greater than this 4% allowance at 4.6%.

Table 1. Value of the 89 boards for each of the grade evaluation methods (May 9, 2000 Hardwood Market Report).

Evaluation Method	Value
Line Grade	$310
NHLA Grade	$259
Digitized Grade	$247
Automated Grade	$244

Board-by-Board Accuracy

One advantage offered by automated lumber grading is higher board-by-board grade accuracy. Figure 2 compares the grading accuracy between the *Line* and *Automated* grade methods. On a board-by-board basis, the *Automated* method grades 63 percent of the boards correctly compared to the *Line* method, which grades only 48 percent of the boards correctly. Note that this board-by-board comparison is much stricter than the board distribution comparison shown in Figure 1, because some incorrectly downgraded boards are balanced with incorrectly upgraded boards. The reasons for such board-by-board accuracy results will be discussed in the next section.

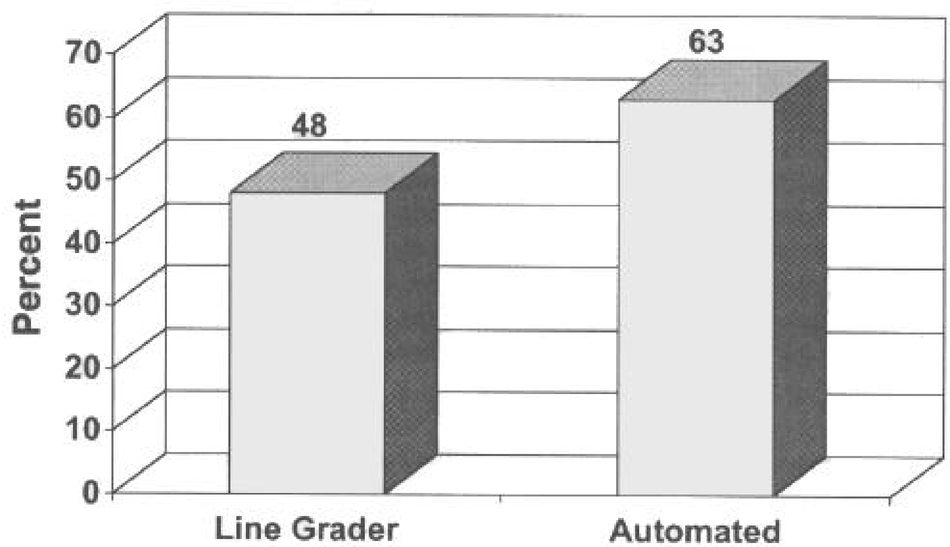

Figure 2. Percent board-by-board grading accuracy comparison between the *Line* grader and the *Automated* grader (Digitized grade assumed to be true grade).

Factors Limiting Automatic Grading Accuracy

Defining the "ground truth" or true grade of a board is still a subjective process. For example, in this study, eight of the NHLA-graded boards were later assigned a different grade by the NHLA inspector. More accurate consideration of board sidebend (crook) in cutting unit calculations was the primary reason. Automated grading can significantly increase grading consistency through more precise measurements and calculations. Since the *Automated* grading method uses UGRS, which employs a strict and literal interpretation of the NHLA grading rules, it is suggested that an evaluation procedure similar to the *Digitized* grading method would be the least biased method of evaluation. Nevertheless, establishing a completely unbiased "ground truth' for accurate grading system testing and feedback is difficult. Regardless of any inherent bias found in this study, the following factors contributed significantly to grading discrepancies and will require more careful and precise definition to ensure commercially viable lumber grading technology.

Sidebend. Board sidebend can have a significant impact on the calculation of available cutting units. If sidebend, even a small amount, is ignored, the calculation of available cutting units has the tendency to increase. Since an automated system can make precise geometrical calculations, it will tend to downgrade such boards relative to human graders.

Surface Measure. Differences in the surface measure can cause a grade difference if the measurements for the surface measure calculations are off by even a small amount. For example, the surface measure can be off by 1 depending on how precise a human grader measures the width of the board. Therefore, a larger or smaller surface measure estimate could possibly downgrade or upgrade a board, respectively. This raises the question as to why there is a discrepancy in the surface measures. The boards may be close to the borderline between two surface measures and a fraction of an inch or rounding may move the board to one surface measure or another. Since an automated system can make precise length and width measurements, it would easily be able to handle an area measurement system with much higher resolution than the existing manual system.

Cutting Units. In many cases, the available cutting units in a board may be close to the borderline between two grades. For example, if 65 percent of the board's surface measure were available for clear cutting units, it would be graded as a #2 common. But it would be very close to a #1 Common, which requires 67% of the board's surface measure. Making a critical grading feature smaller or larger (say one quarter of an inch) can mean the difference between two grades. Since an automated grading system can make precise cutting unit measurements and calculations, it would be easy to report available cutting units along with board grade. Knowing the percent of the board that is available for cutting would be valuable information when designating the optimum use of a particular board.

Small defects, stain and mineral streak. Small defects, such as pin knots and worm holes, stain and mineral streak, are sometimes difficult to detect at production speeds, and it may be subjective as to when these features are considered grading defects. These defects are oftentimes detected by an automated grading system and included in the defect map as a critical defect. In this study, stain or mineral streak was not included as a grading defect in the UGRS-graded boards. However, the most significant error observed in the *Automated* lumber grading system was misclassification of certain stain and mineral features as critical knot defects. This error is illustrated in Figure 3 where a bum mark in the wood is falsely detected as a set of knots.

Grading Rough-Green Hardwood Lumber

Figure 3 illustrates how innocuous surface marks on dry surfaced lumber can sometimes be confused with lumber grading defects. Such misclassification errors will be an even greater problem for rough, green lumber where surface conditions can vary widely. Figure 4 illustrates this potential problem by showing a typical image of a red oak board collected at the green chain. The board contains black sawmarks and a portion of the board surface has begun to dry, creating a lighter appearance. These conditions pose a significant challenge for automated lumber grading systems. Further R&D will be needed to find the most appropriate scanning technologies and develop the computer software that can see through such highly variable "noise" that can be present in wood.

Figure 3. Surface marks misclassified as critical grading defects.

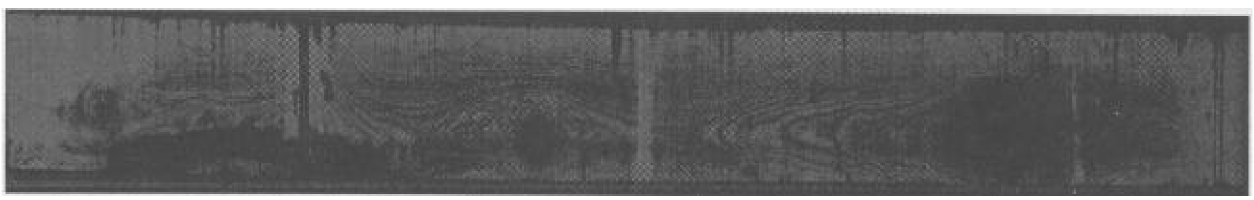

Figure 4. Surface marks present in rough, green red oak lumber.

CONCLUSION

Machine lumber grading systems will be making their debut in the next several years. The primary cost savings from such a system will be realized by producing a more uniformly and consistently graded product and by producing a higher value product through optimum lumber remanufacturing. Technology is now available to create such systems. However, adapting this technology for lumber grading applications will take several years. Successfully delivery of such grading systems to the end user will depend upon equipment manufacturers, mill managers, and operators having a good understanding of the level of sophistication of technology and the associated learning curve required to handle the extremely variable material called "wood."

Using a multiple sensor lumber scanning system developed at Virginia Tech, a preliminary automated lumber grading study was conducted on an 89-board sample of dry, surfaced red oak lumber. On both board-by-board and lumber value bases, the automated lumber grader was found to be more accurate and consistent than line graders. Most automated lumber grading discrepancies resulted from board geometry issues (board crook, surface measure rounding, calculation of cutting units, etc.). As far as the lumber scanning technology is concerned, defect recognition improvements should focus on better methods to differentiate surface discolorations from critical grading defects.

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