

## Hardwood Lumber Scanning Tests to Determine NHLA Lumber Grades

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### ABSTRACT

*This paper concerns the scanning, and grading of kiln-dried hardwood lumber. A prototype system is described that uses laser sources and a video camera to scan boards. The system automatically detects defects and wane, grades the boards, and then searches for higher value boards within the original board. The goal is to derive maximum commercial value based on current market lumber prices. This paper presents the results of an empirical test in which the system's grading decisions are compared with those assigned by a human expert. The tests involved 86 yellow-poplar boards and 90 red oak boards. The automated system assigned higher grades for 17% of the boards, and lower grades for 43% of the boards. The main cause of disagreement was the presence of stains on the board, both natural and mechanical, which were occasionally classified by the scanning system as defects. The system also recommended additional edging or trimming on 42% of the boards to increase the grade and value of the boards. Overall, the automated system performed well on typical cases of planed, kiln-dried boards.*

### 1. INTRODUCTION

Companies in the U.S. and Canada buy and sell hardwood lumber using the National Hardwood Lumber Association (NHLA) grading rules (National Hardwood Lumber Association 2007, American Hardwood Export Council 2000). U.S. and Canadian hardwood companies also use the NHLA grading rules to trade lumber on the international market. The value of the lumber per board foot (12·12·1 inch volume measure) can be large depending on the grade of each piece of lumber. Table 1 shows the values for kiln-dried red oak and yellow-poplar lumber by grade. The values are quite different by species and grade. The board grades are based on a visual assessment of the boards by a lumber grader (a person). A board's grade depends on estimates of its surface area, the type and placement of defects, grade cuttings, and current market lumber prices. Table 2 presents some of the basic rules for F1F, 1 Common, and 2 Common lumber. Exceptions to these rules exist and there are some species specific rules, but the most important rules are shown in Table 2.

Table 1. Prices per 1,000 board feet for 4/4 kiln-dried (net tally) red oak and yellow-poplar lumber (Appalachian Pricing – Area 2, Hardwood Review 2011).

| Species       | Lumber grade |       |     |
|---------------|--------------|-------|-----|
|               | FAS/1F       | 1C    | 2C  |
| Red oak       | 1,450        | 1,090 | 870 |
| Yellow-poplar | 840          | 580   | 475 |

Substantial financial losses can result from improper grading decisions. Both buyers and sellers can lose from over and under estimates of lumber grading. Part of this happens when certified graders are not completely consistent and correct in their grading. This is due in part to subjective estimates of board surface area, cutting sizes, defects and defect sizes, approximate knowledge of market prices, different levels of experience, and fatigue. Some lumber purchasers don't even grade the lumber they purchase leading to

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potential over payments for loads of lumber and resulting lower yields of needed parts when converting the lumber to parts.

Table 2. Basic NHLA rules for FAS, F1F, 1C and 2C lumber (based on the lower grade faces, NHLA 2007).

|  | Lumber grade                              |                             |                          |                                  |
|--|---|-----------------------------|--------------------------|----------------------------------|
|  | FAS                                       | F1F                         | 1 COM                    | 2 COM                            |
| Minimum size board                         | 6''·8'                                    | Same as FAS                 | 4''·6'                   | 3''·4'                           |
| Minimum size cuttings                      | 4''·5'<br>3''·7'                          |                             | Better face to grade FAS | 4''·2'<br>3''·3'                 |
| Basic yield                                | SM·10<br>83 <sup>1</sup> / <sub>3</sub> % | Poor face to grade 1 Common |                          | 66 <sup>2</sup> / <sub>3</sub> % |
| Formula to determine # of cuttings allowed | SM÷4<br>(4 max)                           |                             | (SM+1)÷3<br>(5 max)      | SM÷2<br>(7 max)                  |

\* SM: Surface Measure is the surface area of the board in square feet

Automation of the tasks described above is essential for achieving maximum value from the raw material as well as for the conservation of the material. In an attempt to address these issues, we have developed a prototype system that scans hardwood boards and automatically detects wane and defects (Lee et al. 2000, 2001, 2003a, 2003b, 2003c). Using defect information and board dimensions, the system grades the boards using NHLA grading rules and searches for upgrade edging and trimming modifications to the boards (Schmoldt et al. 2001). Automated grading software developed by Klinkhachorn et al. (1988, 1992) has been incorporated into the system.

Although originally developed for rough (unplaned), green lumber, this lumber scanning system also has proved to be effective in processing planed, kiln-dry boards. This paper presents the results of an empirical test of the system. Planed, kiln-dried red oak and yellow-poplar boards were processed by the system, and the resulting grade assignments were compared with the grades that were assigned manually by a certified company grader.

## 2. PROTOTYPE SCANNING SYSTEM

Figure 1 contains a photograph of the scanning system that has been used in this study (Lee et al. 2003b, 2003c). This prototype uses pinch rollers to move boards at a rate of approximately 2ft/s (61cm/s) under three laser sources and a video camera. The system was designed to be relatively small so that it could be transported to other sites for demonstrations. Scanning system speeds of 3-4ft/s or faster would be desired in industrial hardwood lumber applications.

The camera in the system is aimed vertically downward and is positioned to capture a field of view that is 16 inches (41cm) wide. Image resolution, in both cross-board and down-board directions, is 96pixels/inch, which is approximately 0.26mm per pixel. The laser sources are solid-state devices, producing fan-shaped sheets of light. Two of these sources are mounted at the sides to provide reflectance data with the illumination coplanar with the optical axis of the camera and perpendicular to the direction of travel. The third laser is mounted downstream of board movement and it is used to measure thickness (profile) information through triangulation.

The system operates by first detecting wane and then identifies clearwood and defects on the non-wane portion of the board. On planed and dried boards, however, wane is rarely present. For defect detection and identification, the system uses a modular approach that employs several different artificial neural networks (ANN). One of these, a multilayer perception (MLP), attempts to identify clearwood pixels. A second ANN, known as a radial-basis-function network (RBFN), identifies knots and decay. A third ("competitive") network makes the final decision on a pixel-by-pixel basis. The system next analyzes shapes of defects to distinguish splits from voids and also to determine mechanical stains. Because of the typically dark color, stains present an interesting challenge to the system. Two-dimensional shape information is used to distinguish mechanical stains (such as saw and planer burns) from decay. All of these activities can take up to 16 seconds depending on the number of defects. However, computer upgrades would reduce processing time.



Figure 1. A prototype scanning system for hardwood lumber. This was originally designed to detect wane and surface defects in unplanned boards.

Lumber grading and potential upgrading edging and trimming locations are determined using a branch-and-bound search technique (Schmoldt et al. 2001). After the board is graded, we then see if the board can be upgraded based on value decisions. Instead of using a prohibitive exhaustive search on the board, the existing method evaluates individual cut adjustments in sequence, adjusting each inward on the board. The result is not guaranteed to be optimal but is typically close to optimal and is found in about 4 seconds on average. Often, the original board is not modified. This search speed is dramatically faster than an exhaustive search.

The hardwood lumber grades are illustrated by the American Hardwood Export Council in a publication (American Hardwood Export Council 2000) using the National Hardwood Lumber Association grading rules (Table 2, National Hardwood Lumber Association 2007). The grades considered here are known as F1F (which derives from “First and Seconds – 1 Face”), Number 1 Common, Number 2 Common, and Number 3 Common (in order of decreasing quality). The assignment of the correct grade is important because each grade has a different monetary value (Table1).

The current system controller is a 360MHz Pentium II PC with 128MB of main memory. Processing time per board depends on the number of defects. Wane detection, defect detection and identification, and grading typically require less than 20 seconds per board (after completely scanning the board of this dimension). As stated, a newer computer could reduce processing times.

### 3. EXPERIMENTAL RESULTS

Figure 2 shows some example scanned images and the defect-detection results. These examples demonstrate that our scanner and defect-detection software works apparently well on typical cases of planed, kiln-dried boards. There are several cases where the shape-analysis part of the system did not correctly identify stains (planer burn marks), as shown in the third example of the figure (red oak – F1F board).

In these experiments, the MLP alone yielded an accuracy of 91.2% in identifying clearwood, and the RBFN alone identified knots and decay with an accuracy of 92.7%. When combined with the competitive network, the overall pixel-wise accuracy improved to 96.7%.

Table 3 shows the results of the lumber grading and potential upgrading. Eighty-six yellow-poplar board faces were scanned and analyzed. Almost 50% of the board faces received the same or a higher grade than the company grades, and 43% of the boards could be upgraded to a higher and more valuable grade by additional edging or trimming as determined by our software. For the 90 red oak board surfaces analyzed, 64% received the same or a higher grade. Upgrading was possible for 41% of the boards mainly through additional edging or trimming recommended by the software.

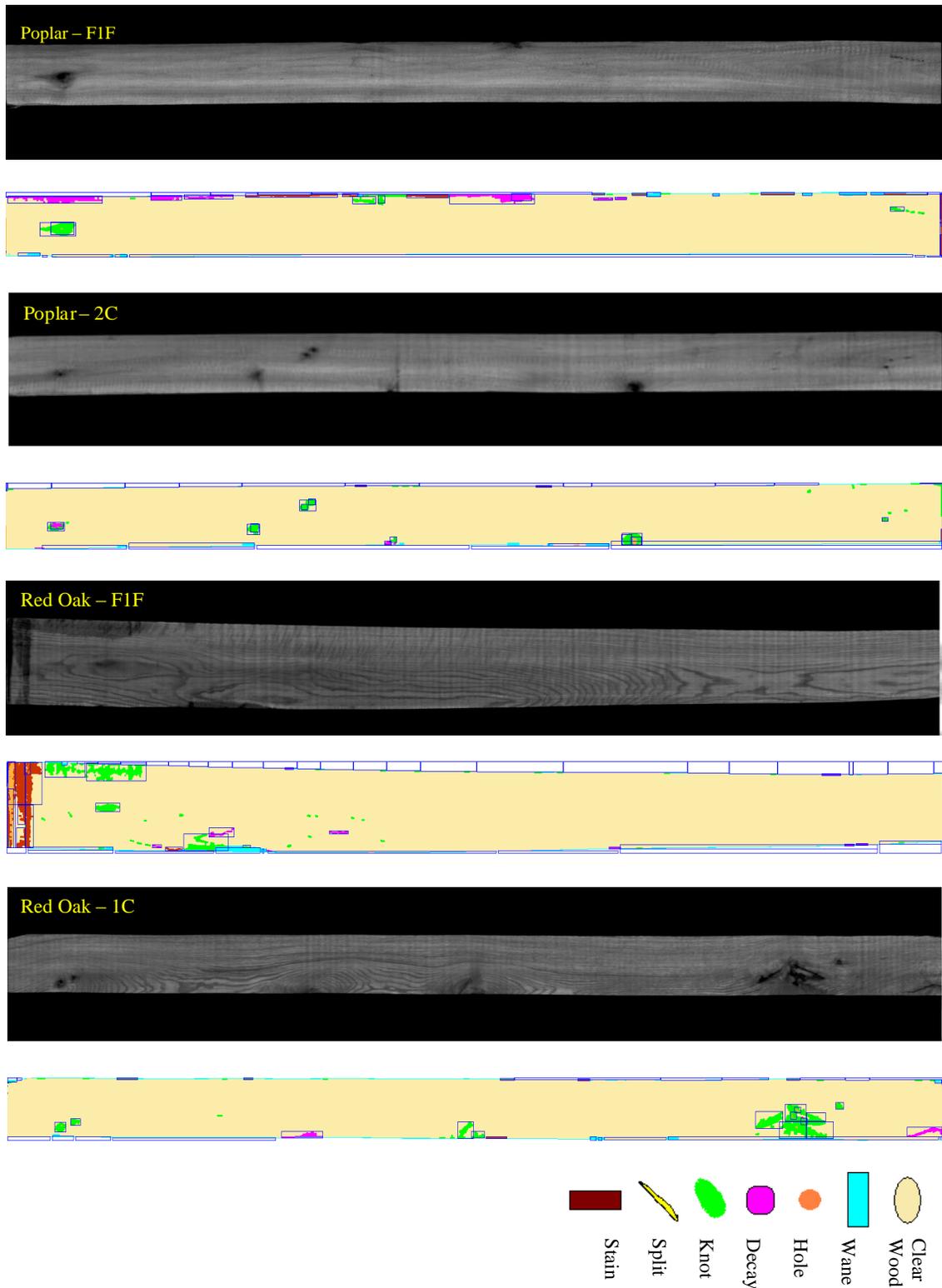


Figure 2. Experimental results for four sample poplar and red oak boards. Underneath each intensity image is color-coded representation of the processed results. Bounding boxes indicate detected defects. Small defects also are detected but are not considered significant for grading and so they are not fed into the grading software.

While most of the higher grades are debatable, as the grading outcomes may vary from one grader to another, the reasons for lower grades assigned by our software are clear. The system occasionally classified natural stains as defects such as knots or decay. Such natural stains are more common in yellow-poplar, as shown in Figure 3. The other major cause of downgrades was mechanical stains. The shape analysis by the system failed in some cases to identify stains from initially classified knots or decays. One such example is shown in Figure 4.

Table 3. Lumber grading results from the company grading and from our automated system. The automated system software graded each board, and in some cases recommended additional edging or trimming to achieve upgrades. Grades FAS and F1F are considered similar for this analysis.

| Species       | Company graded board | No. of boards | Same grade | Scan & grade vs. company grade |             | Upgrade possible |
|---------------|----------------------|---------------|------------|--------------------------------|-------------|------------------|
|               |                      |               |            | Higher grade                   | Lower grade |                  |
| Yellow-poplar | FAS                  | 36            | 17         | 0                              | 19          | 15               |
|               | 1C                   | 29            | 1          | 8                              | 20          | 15               |
|               | 2C                   | 21            | 14         | 2                              | 5           | 7                |
|               | <i>Total</i>         | 86            | 32         | 10                             | 44          | 37               |
| Red Oak       | FAS                  | 27            | 22         | 0                              | 5           | 3                |
|               | 1C                   | 39            | 1          | 14                             | 24          | 21               |
|               | 2C                   | 24            | 16         | 5                              | 3           | 13               |
|               | <i>Total</i>         | 90            | 39         | 19                             | 32          | 37               |

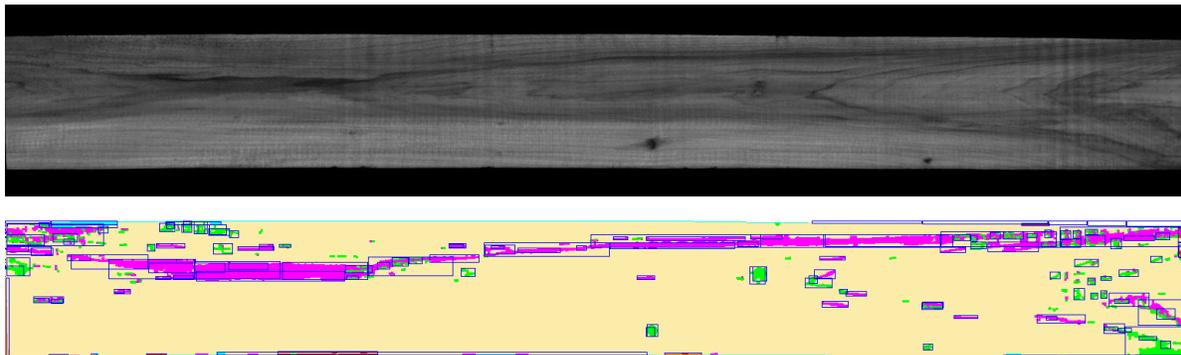


Figure 3. A yellow-poplar board with natural stain that has been classified as decay or knots by the automated system. An NHLA grader graded this board as F1F, but the system graded it as 3 Common.

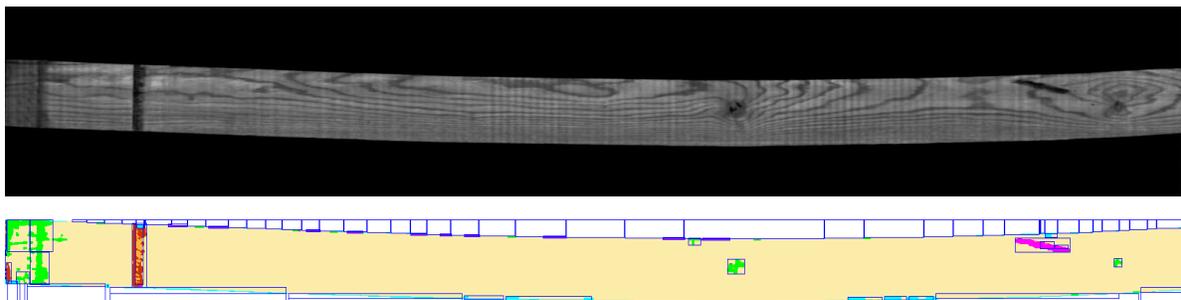


Figure 4. A red oak board with mechanical stain at the left end of the image, which the system did not identify. An NHLA grader graded this board as 1 Common, but the system graded it as 3 Common because the stain regions were assumed to be defects.

#### 4. DISCUSSION

The grading software system has been shown to successfully scan, reconstruct, grade, and process yellow-poplar and red oak planed kiln-dried lumber. The ability to evaluate each board for upgrading by additional edging or trimming will be important to sawmills or lumber distributors.

Additional work is needed to evaluate the reasons why a significant number of the boards (43%) were graded lower by our system than by the company graders. Natural stain, in particular, presents a difficult problem because it can be difficult to distinguish from defects based on shape and intensity alone. The ability of our system to accurately measure grading cuttings may be better than can be performed by human graders. We need to recheck the boards to see if the human graders were wrong in their assessment, or if the software has a problem in scanning, reconstruction, and grading.

#### 5. CONCLUSIONS

This paper has described a prototype system that is capable of scanning and evaluating hardwood boards. The system detects defects and wane, recommends edging and trimming solutions, and estimates the resulting lumber grades. The main contribution of this effort is a comparison of this system's performance with grades that were assigned manually by a person for planed kiln-dried hardwood lumber.

The system software was evaluated with 86 yellow-poplar boards and 90 red oak boards, using the decisions made by an NHLA grader as ground truth. As the boards were scanned, defects were correctly identified on a pixel-by-pixel basis with an accuracy of 96.7%. Based on the defect types and locations, sawing decisions were generated automatically and grades were assigned to the boards that would result (No physical sawing was performed).

For 40% of the boards, both our software and the NHLA trained grader assigned the same grades. This overall accuracy rate seems quite low until one considers the fact that no system of this type can be expected to achieve perfect accuracy and that certified graders are not always in agreement. When we examined the sources of disagreement, we discovered that the automatic scanning system occasionally classified natural stains incorrectly as defects (decay or knots), and this adversely affected the grading and sawing decisions. The other major cause of downgrades was mechanical stains, which the system occasionally classified as defects. Downgrades such as these accounted for 43% of the incorrect results, and this problem could be addressed by devoting some time to improve the system's ability to identify natural and mechanical stains. The company grades also could be incorrect and we may have additional independent graders look at our lumber sample.

The assignment of higher grades by our software for 16% of the boards deserves more study, perhaps including assessment by several NHLA experts. Subjectively, the performance of the system was good. Overall, our examples have demonstrated that our classification software works well on typical cases of planed and dried boards.

The prototype system also showed its worth by suggesting that 42% of the boards could be edged or trimmed to increase the grade and value of the boards. This would be a major plus for a lumber seller. It also should be restated that this system could also be used by lumber buyers to validate lumber purchases.

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