Automated Grading, Upgrading, and Cuttings Prediction of Surfaced Dry Hardwood Lumber

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Abstract

This paper concerns the scanning, sawing, 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, searches for optimal sawing solutions, and then estimates the grades of the boards that would result. The goal is to derive maximum commercial value based on current market prices. This paper presents the results of a recent empirical test in which the system's grading decisions are compared with those assigned by a human expert. We also assess the potential of cuttings from the lumber by board grade. The test involved 86 yellow poplar boards and 90 red oak boards. The automated system assigned higher grades for 17% of the boards, and it assigned 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 and dried boards.

1. Introduction

In today's hardwood sawmills, most cutting and grading decisions are performed manually. Edger and trimmer operators typically make sawing decisions based on fast visual examinations of each board, or the processors have scan-controlled saws that base decisions on just wane and void (incomplete information). Each board is then assigned a grade manually, based on a visual assessment of the board. A board's grade depends on estimates of its surface area, the type and placement of defects, grade cuttings and current market prices for lumber.

Unfortunately, substantial losses can result from improper sawing and grading decisions. For example, value losses from excessive edging alone have been estimated at 30% [2], and losses from suboptimal edging and trimming were estimated at 35% in one case study [11]. Similarly, certified graders are not completely consistent in their work, and this is due in part to subjective estimates of board surface area, approximate knowledge of market prices, different levels of experience, and fatigue.

Automation of the tasks described above is essential for creating products of high value, while accurately graded for increasing profits, and for conservation of raw materials. In an attempt to address these issues, we have developed a prototype system that scans wooden boards and automatically detects wane and defects [5-9]. Using defect information and board dimensions, the system searches for optimum edging and trimming locations [12]. Recently, automated grading software developed by Klinkhachorn, et al. [3, 4] has been incorporated into the system. The combined software package is known as AHLGUCS (Automated Hardwood Lumber Grading, Upgrading, and Cuttings Prediction System).

Although originally developed for rough (unplaned) green lumber, this lumber scanning system has also proved to be effective in processing planed dry boards. This paper presents the results of a recent 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 grader. We also processed the scanning results in a lumber-to-cuttings simulator to predict cutting yields for products such as flooring, furniture and cabinets.

The rest of this paper is organized as follows. Section 2 briefly describes the scanning system that we have developed. Section 3 presents details of the empirical study that has recently been completed. Section 4 offers a critical assessment of the results, and Section 5 presents concluding remarks.

2. Prototype scanning system

Figure 1 contains a photograph of the scanning system that has been used in this study [6, 7]. This prototype uses pinch rollers to move boards at a rate of approximately 2 ft/s (61 cm/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.

The camera in the system is aimed vertically downward, and is positioned to capture a field of view that is 16 inches (41 cm) wide. Image resolution, in both cross-board and down-board directions, is 96 pixels/inch, which is approximately 0.26 mm 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 identifying 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 perceptron (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. An overview of system operation is shown in Figure 2.

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.

Edging and trimming locations are determined using a branch-and-bound search technique [12]. Instead of using a prohibitive exhaustive search, 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. The resulting search speed is dramatically faster than exhaustive search.

The hardwood lumber grades are illustrated by the American Hardwood Export Council in a publication [1] using the National Hardwood Lumber

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

Association grading rules [10]. 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 vastly different monetary value.

The current system controller is a 360 MHz Pentium II PC with 128 MB 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).

3. Experimental results

Figure 3 shows some example scanned images and the defect-detection results. These examples demonstrate that our scanner and defect-detection software works well on typical cases of planed and 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

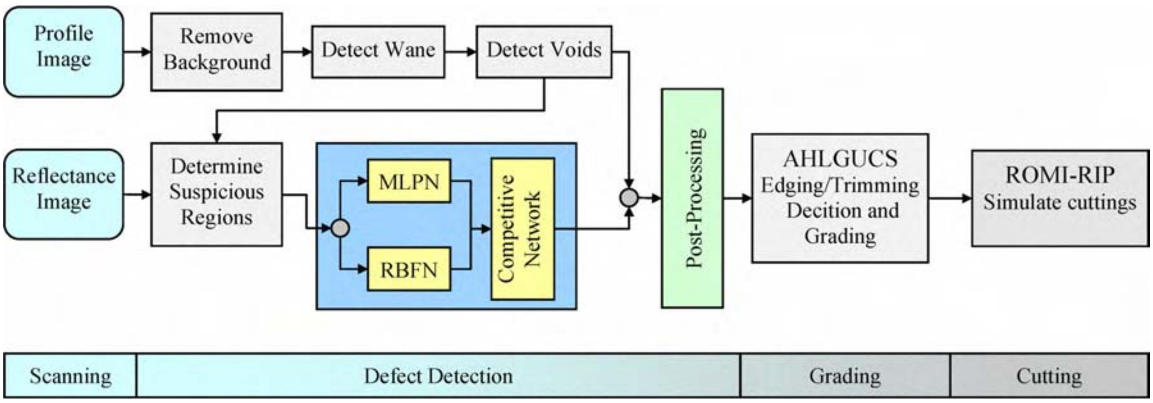

Figure 2. Processing steps and the algorithms applied - from data collection (left) to the optimized cutting plan (right).

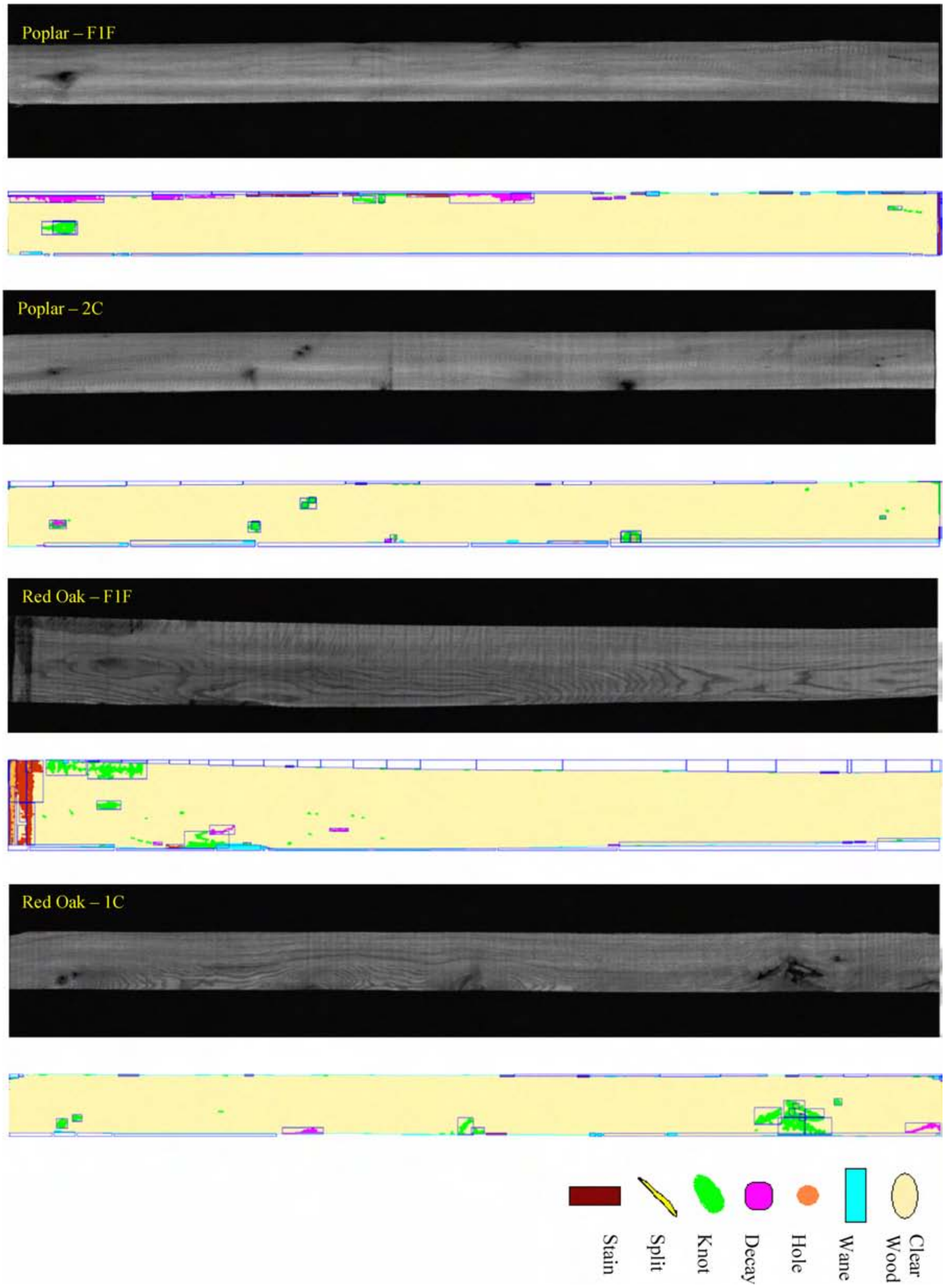

Figure 3. Experimental results for 4 sample poplar and red oak boards. Underneath each intensity image is color-coded representation of the processed results. Bounding boxes indicate detected defects. Small defects are also detected, but are not considered significant for grading and so they are not fed into the grading software. These examples show that our classification software works well on typical cases of planed and dried boards.

accuracy of 92.7%. When combined with the competitive network, the overall pixel-wise accuracy improved to 96.7%.

Table 1 shows the results of the lumber grading part of the AHLGUCS system. Eighty-six yellow poplar board faces were scanned and analyzed by AHLGUCS. 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 AHLGUCS 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, through additional edging or trimming recommended by AHLGUCS.

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 AHLGUCS 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 4. 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 5.

We have also used the ROMI-RIP software [13] to simulate production of cuttings from the boards. This analyzes how the boards can be used to produce parts for flooring furniture, cabinets and other products, as shown in Figure 6.

4. Discussion

The AHLGUCS 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 very important to sawmills or lumber distributors. Having the ability to predict cutting yield is also important and a good marketing plus.

Additional work is needed to fully evaluate the reasons for a significant number of the boards (43%) to be graded lower by our AHLGUCS system than had been graded by 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. Possibly this problem could be addressed by a careful evaluation of burn patterns, or by incorporating an additional scanning tool into the system.

The ability of our system to accurately measure grading cuttings may be better than can be performed by human graders. The boards should be checked again to see if the human graders were wrong in their assessments, or if the software has a problem in scanning, reconstruction, or another area.

Table 1. Lumber grading results from the company grading and from our automated system. The AHLGUCS 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.

			Scan & Grade vs. Company Grade			
Species	Company Graded Board	# of Boards	Same Grade	Higher Grade	Lower Grade	Upgrade Possible
Yellow Poplar	FAS	36	17	0	19	15
	1C	29	1	8	20	15
	2C	21	14	2	5	7
	Total	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
	Total	90	39	19	32	37

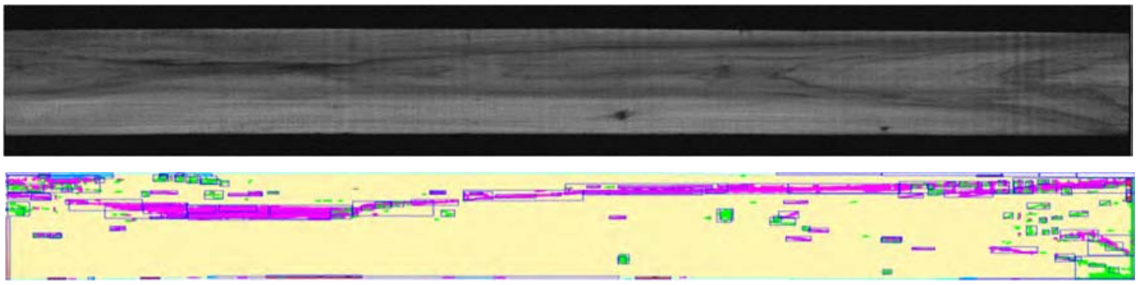

Figure 4. A yellow poplar board with natural stain that has been classified as decay or knots by the automated system. An NHLA grader graded this board as F1F, but the system graded it as 3 Common.

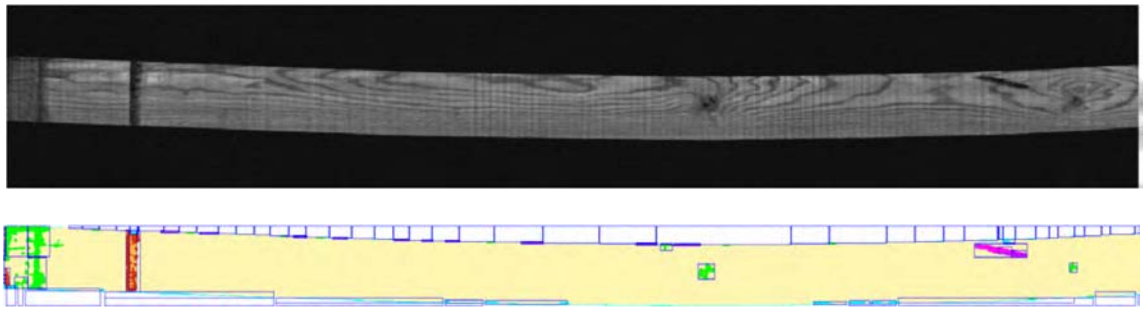

Figure 5. A red oak board with mechanical stain at the left of the image, which the system did not identify. An NHLA grader graded this board as 1 Common, but the system graded it as 3 Common because the stain regions were assumed to be defects.

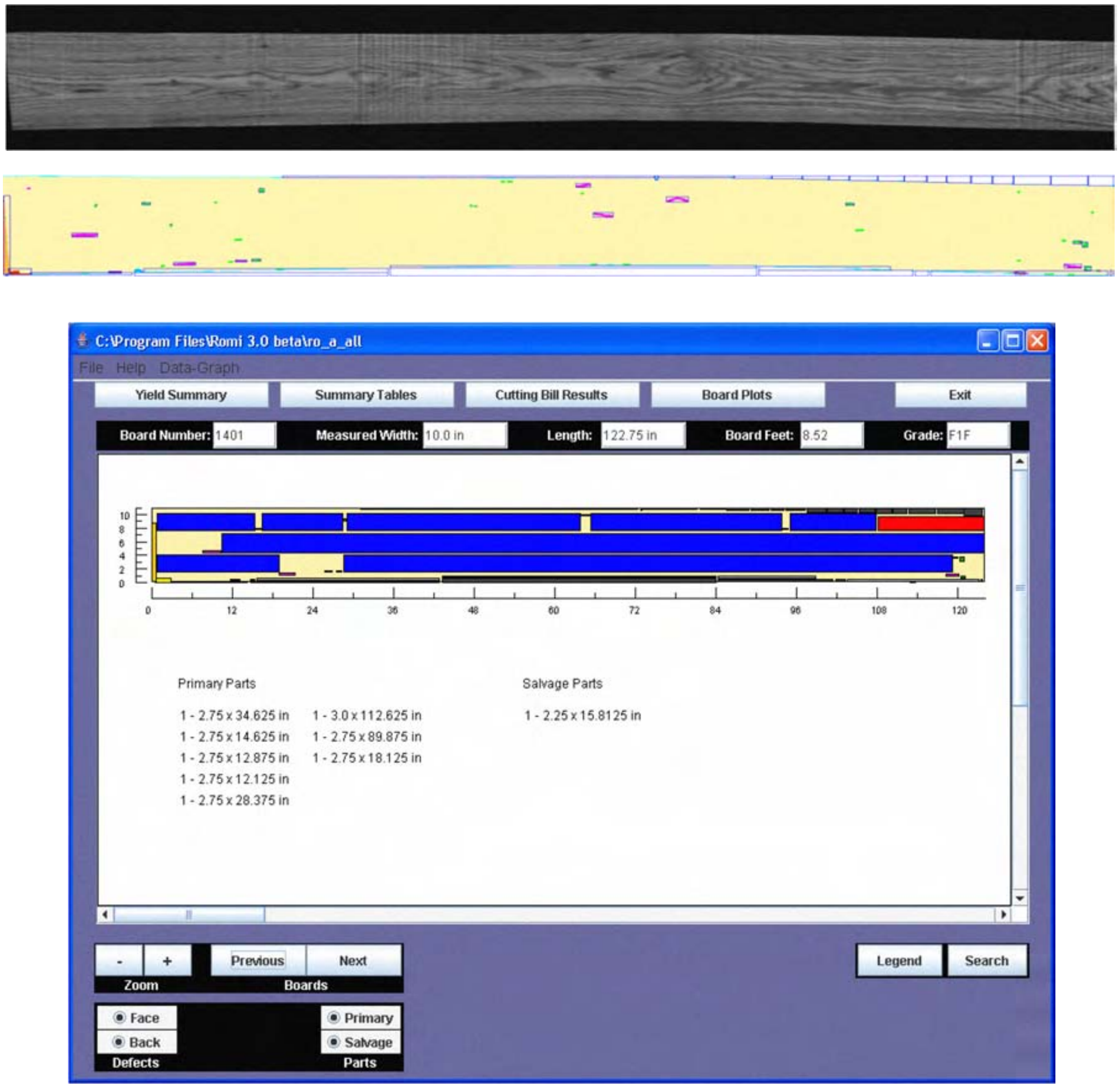

Figure 6. An example of ROMI output [13]. An F1F yellow oak (shown at the top of the figure) was simulated with the ROMI-RIP program to estimate optimized cutting.

5. Conclusion

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 paper is a comparison of this system's performance with grades that were assigned manually for planed kiln-dried hardwood lumber.

The AHLGUCS 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 AHLGUCS 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 sawing and grading 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 could also be incorrect and we may have additional independent graders look at our lumber sample.

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

6. Acknowledgements

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7. References

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