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AUTOMATIC EDGING AND TRIMMING OF HARDWOOD LUMBER

by

D. E. Kline
Assistant Professor
Department of Wood Science
and Forest Products

E. M. Wengert
Professor
Department of Wood Science
and Forest Products

P. A. Araman
Project Leader
Southeastern Forest Experiment Station
USDA Forest Service

Virginia Polytechnic Institute and State University
Blacksburg, Virginia, USA

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SUMMARY:

Studies have shown that there is a potential to increase hardwood lumber value by more than 20 percent through optimum edging and trimming. Even a small portion of this percentage can boost the profitability of hardwood lumber manufacturers substantially. The objective of this research project is to develop an automated system which would assist in correct edging and trimming of hardwood lumber, thereby, increasing lumber value. This paper discusses computer vision and automation design issues for hardwood edging and trimming, potential benefit, current progress and future research plans.

KEYWORDS:

COMPUTER VISION, AUTOMATION, HARDWOOD LUMBER MANUFACTURING

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Automatic Edging and Trimming of Hardwood Lumber

D. Earl Kline Eugene M. Wengert Philip A. Araman

INTRODUCTION

There are over 3500 sawmills producing hardwood lumber in the Southeastern portion of the United States for the household furniture and cabinet industries. To stay in business, these sawmills must be able to produce the highest possible grade lumber from any given saw log. Sawmill edging and trimming operations have a substantial effect on the grade of lumber produced. Approximately 20 percent of the lumber produced must be edged and nearly all lumber must be trimmed. Previous studies (Flann and Lamb, 1966; Bousquet, 1989) have indicated that there is a potential to increase lumber grades by over 20 percent through optimum edging and trimming. Such a large potential can translate into millions of dollars for hardwood lumber manufacturers.

Present trends, such as increasing costs and limited supplies of high quality logs, have been making hardwood lumber manufacturers increase efforts to maximize the utilization of this raw material. Standard hardwood edging and trimming operations are less than optimum because of the complexity of the grading rules, the decision process, operator skill, operator fatigue, and the precision of mechanical setworks. The optimization of edging and trimming operations must involve some degree of automation. That is, some type of system must be designed that can scan a board to sense important hardwood features, make correct edging and trimming decisions, and then control downstream edgers and trimmers with minimal operator intervention.

For various reasons, the hardwood lumber industry has been slow to adopt computer and automation technology in its processing operations. One reason is that automated systems for hardwood lumber processing must be able to reliably detect many hardwood lumber features such as dimension, wane, knots, splits, holes, stain, and decay. Automatic detection of these random features that occur on lumber is a very unique and complex problem. Another reason is that the volume of production in a hardwood mill is typically not large enough to economically justify the investment of high-cost automation equipment.

The overall objective of this research project is to design and develop an automated edging and trimming system for hardwood lumber manufacturing. This paper discusses computer vision and automation design issues for hardwood edging and trimming, potential benefit of such a system, current progress and future research plans.

HARDWOOD LUMBER MANUFACTURING

The typical components and material flow for a hardwood sawmill in the Southeastern region of the United States is shown in Figure 1. Actual mill layouts can vary substantially depending on the size and goals of the sawmill. However, Figure 1 shows the basic components of a hardwood sawmill which include a debarker, a headrig, an edger, a resaw, and a trimmer. Logs enter the debarker to remove bark and debris that may prematurely dull saw blades. Debarked logs wait on a log deck for primary breakdown at the headrig. The headrig, which employs a circular or a band saw, breaks the log down into boards. To increase headrig production by reducing the number of headrig passes on a given log, a gang resaw is used to assist in cutting log cants into lumber. Boards with wane (non-straight edges) are routed to the edger where wane and other edge defects that affect grade are removed. The proportion of boards that require edging depends upon the sawing methods employed at the mill. Boards from the headrig, edger, and gang resaw are then routed to the trim saw to remove end defects that affect grade. In certain cases, some gang resawn boards are routed to the edger to remove wane. In any case, nearly every board is processed at the trim saw. Finally, edged and trimmed lumber is graded, sorted and stacked.

Achieving maximum hardwood lumber value depends on balancing between lumber volume and lumber grade. Although many elements affect hardwood lumber value, edging and trimming practices have one of the greatest effect that is controllable. However, there are many factors that influence the performance of current edging and trimming operations. Since current edging and trimming operations are labor intensive, the main factors involve the operator including: (a) operator knowledge of hardwood grading rules, (b) operator skill, (c) processing speed the operator must maintain, and (d) operator fatigue. Other factors include machinery maintenance and raw material quality.

Although hardwood lumber manufacturers are recognizing the need to improve edging and trimming operations, very few are able to make improvements. Improved edging and trimming will require some level of automation or computer-aided processing as well as the proper training of the operators. **A** hardwood sawmill in Louisiana recently upgraded its equipment to include an edging optimizer (Griffin, 1989). The mill has achieved a 40 percent production gain given a 20 percent increase in capital investment. Such a large return on investment is one justification to modernize hardwood sawmills.

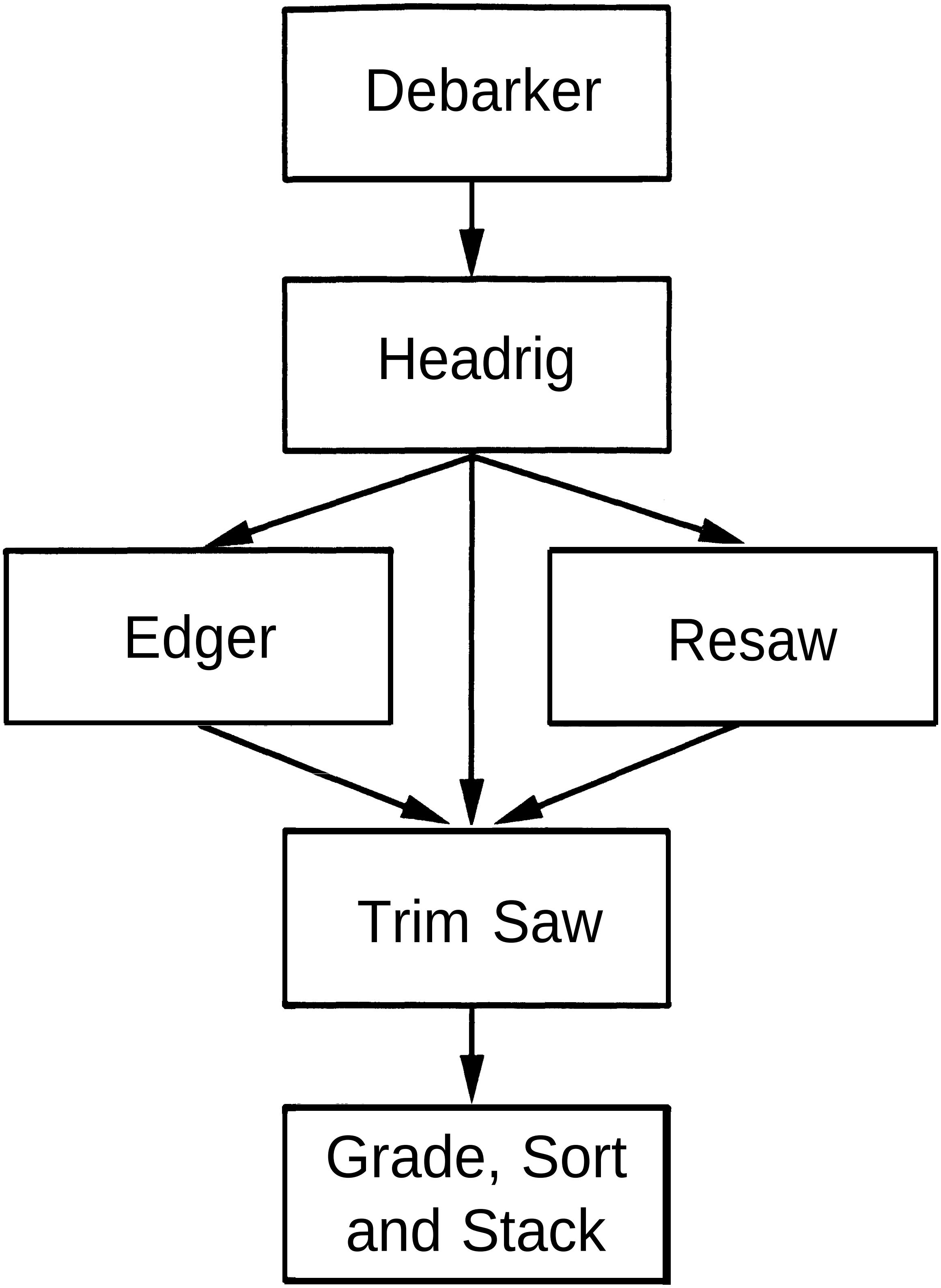

Figure 1. Basic components of a hardwood sawmill.

However, since the company is large (40 million board feet per year), it can afford to adapt costly automation equipment that has typically been used in softwood lumber manufacturing. Such automation equipment will remain costly until systems are developed that specifically address the unique requirements of hardwood lumber manufacturing. Current research efforts are underway to address this need by automating hardwood edging and trimming operations.

AUTOMATIC EDGING AND TRIMMING SYSTEMS

An automated hardwood edging and trimming system involves three basic components (Figure 2): (1) a scanning component to collect board information; (2) a decision-making component that synthesizes board information to make some control decision; and, (3) a mechanical component to carry out the control decision. Each of these components are addressed separately in the following discussion.

Board Scanning Component

The most common type of board scanning system used in modern sawmills contains some type of an optical sensing mechanism. The simplest optical sensing mechanism involves the interruption of the light path between a light source and a detector. More complex optical mechanisms involve the detection of reflected light from some illuminating source such as an incandescent lamp, a laser light source, or even an X-ray source. In any case, optical board scanning systems employ some type of light source and some type of photo sensitive element that can convert the light energy into an array of numbers to represent the board. The type of light source, the type of sensor, and their configuration depend upon the application whether it be board detection, thickness measurement, or the recognition of some feature.

In the application of automating hardwood edging and trimming operations, the scanning system must be able to sense board geometry and as many surface features that are important in determining lumber grade. Board geometry includes length, width, thickness, and wane. Other important features needed to establish lumber grade include knots, holes, stain, mineral streak, decay, splits, and checks. Since a hardwood sawmill typically processes more than one species of timber, the difference in features across different species must be taken into account. Hence, the board scanning must be as flexible and robust as possible, yet simple enough to minimize the cost of the system.

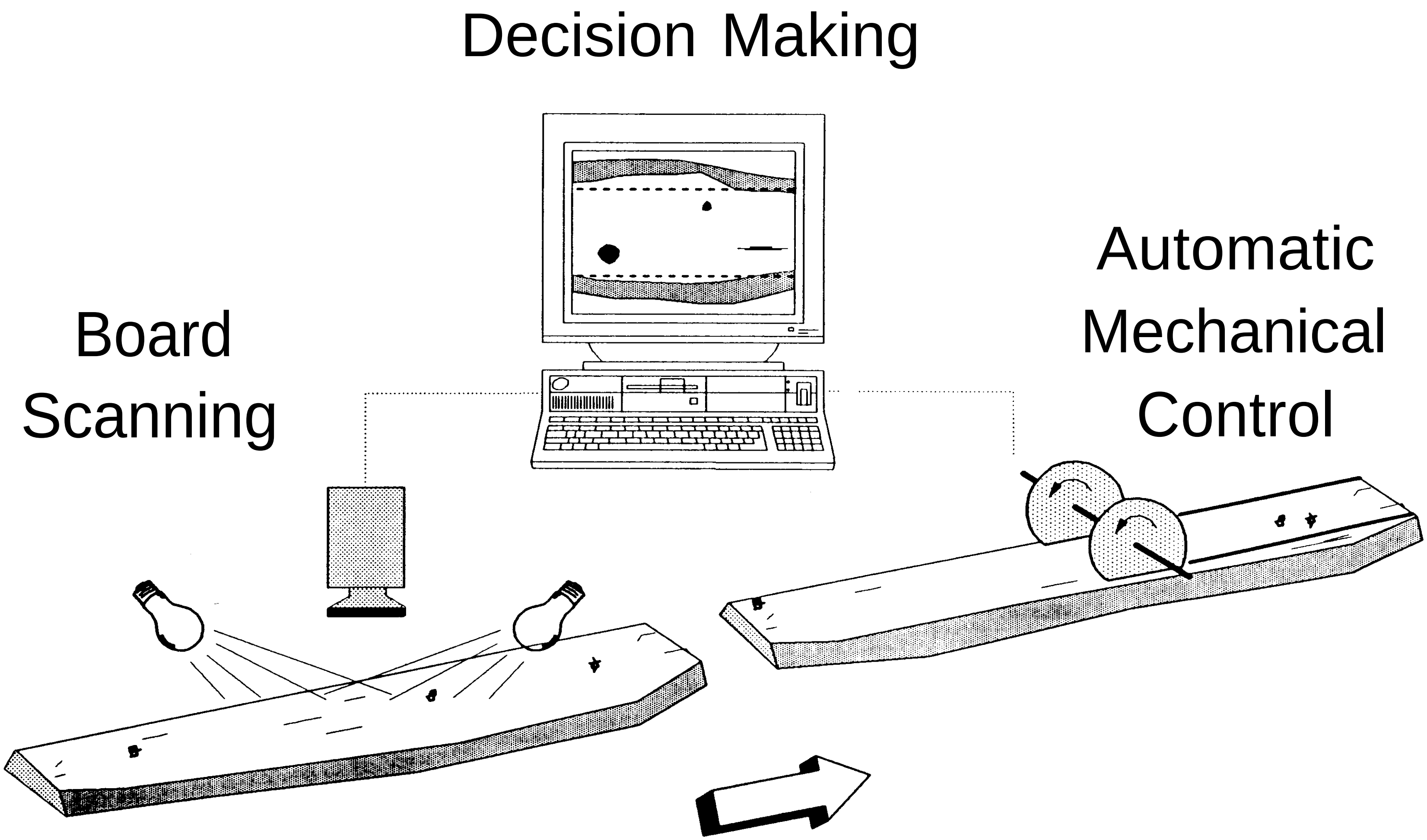

Figure 2. Conceptualization of an automated hardwood edging and trimming system.

Since a hardwood lumber grader relies primarily on human color vision to grade lumber, nearly all of the features in hardwood lumber that affect its grade are detectable using visible light. Computer vision technology can provide a system that can convert this visible light energy into a computer representable form. The computer vision system would consist of a configuration of light sources to illuminate the board and a color camera to sense the reflected light. This system is a relatively simple and inexpensive way to sense a large amount of information. However, the difficult issue is in processing and making use of this vast amount of information. If such board information cannot be processed quickly and effectively, then the overall capability of the computer vision system will be inadequate. This issue of board image processing will be discussed in greater detail in the next section.

Decision-Making Component

The decision-making component is the part of the automated edging and trimming system that utilizes the information obtained from the board scanning component. The effectiveness of the decision-making component depends on the speed and reliability at which the best edging and trimming solution is reached. An "optimal" edging and trimming solution will seldom be achieved if the algorithms used to locate and identify important surface features on lumber are inadequate. Furthermore, if the algorithms are adequate, but require an enormous amount of computing time to reach a solution, then, the overall cost and performance of the system will be prohibitive. Consequently, the decision-making component must be able recognize and locate important hardwood lumber features and must be able to use these features to establish an acceptable edging and trimming solution in a timely and reliable manner.

Board Image Processing and Feature Recognition

Over the past few years, significant progress has been made on developing computer vision algorithms to locate and identify features on hardwood lumber. Conceptually, the vision system software can be subdivided into two components. The first component is a segmentation component. The purpose of this component is to separate pixels of clear wood from pixels that might contain an objectionable feature. The second component is the recognition component. The purpose of the recognition component is to identify the type of feature present. The aim of these computer vision algorithms has been directed toward developing robust algorithms so that the same algorithms can be employed across a variety of species and condition of lumber. More detailed information on the development on these software algorithms can be found in Conners et al. (1989a, 1989 b).

Figures 3 and 4 show an example of applying computer vision algorithms on a sample image of red oak lumber. Figure 3 is a black and white image of the scanned lumber sample. Figure 4 is the result of applying the segmentation and recognition algorithms to separate clear wood from objectionable features and identifying the features in question. In this case features identified are knots and splits/checks. Currently, the software system can recognize four important features: wane, knots, holes, and splits/checks. Also, by selecting the appropriate background color, the software system can easily distinguish between wood and background. The same computer vision algorithms have performed equally well on many hardwood species including white oak, red oak, walnut, cherry, maple, poplar, and hickory without the need for any parameter changes. They have been tested on both rough lumber and surfaced lumber. The algorithms have also been tested successfully on white pine.

While significant progress has been made, the recognition accuracies are not yet good enough for a commercially viable product. One problem concerns knots. Many knots have the same color as clear wood. These knots are difficult to detect during the segmentation operation and even when detected they have proven difficult to identify during the recognition operation. When debarkers remove both the bark and the cambium, a tissue that is always dark in hardwood species, detecting wane can also be a problem. Finally, gum pockets have frequently been identified by the recognition operation as a split or check. In grading cherry, one must be able to distinguish gum pockets from splits or checks. Progress is currently being made in better recognizing gum pockets.

Another major problem in applying these software algorithms to locate and identify important features is in processing all of the board image data within a reasonable amount of time. Suppose that an edger must be able to process an average of 15 boards per minute and that a typical board measures 8 inches wide and 13 feet long. If each side of a board is scanned in color with an along board spatial resolution of 32 pixels per inch and a cross board resolution of 64 pixels per inch, approximately 15 megabytes of information is captured for each board. To maintain an average throughput of 15 boards per minute means that approximately 4 megabytes of color image data must be processed each second. Such a great data processing rate demands that the computational complexity of the software be simple as possible and the computing hardware be fast as possible.

There are several possible methods to reduce the computational complexity of the image processing and feature recognition software. One method is to minimize the amount

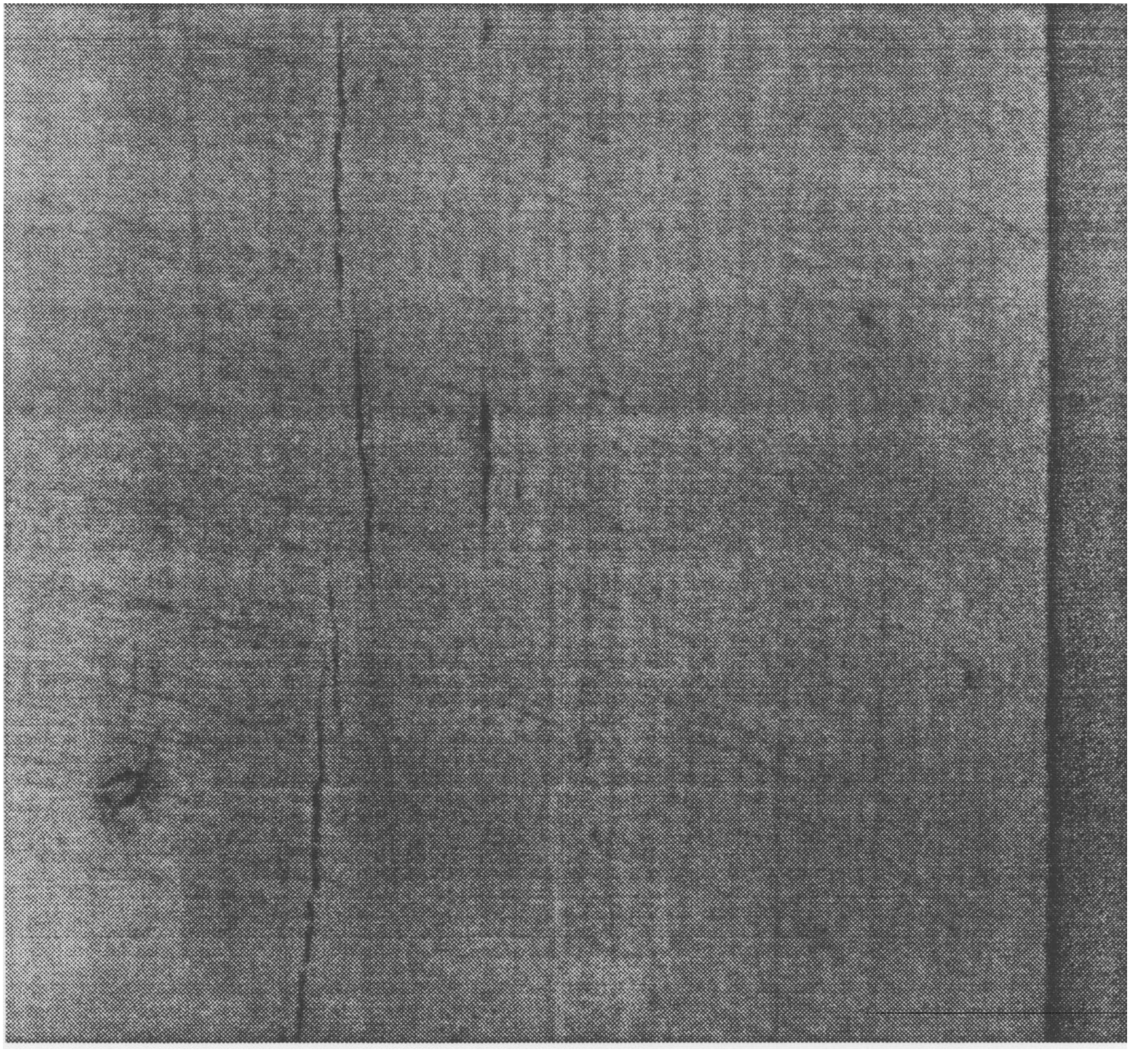

Figure 3. Black and white image of a scanned red oak lumber sample.

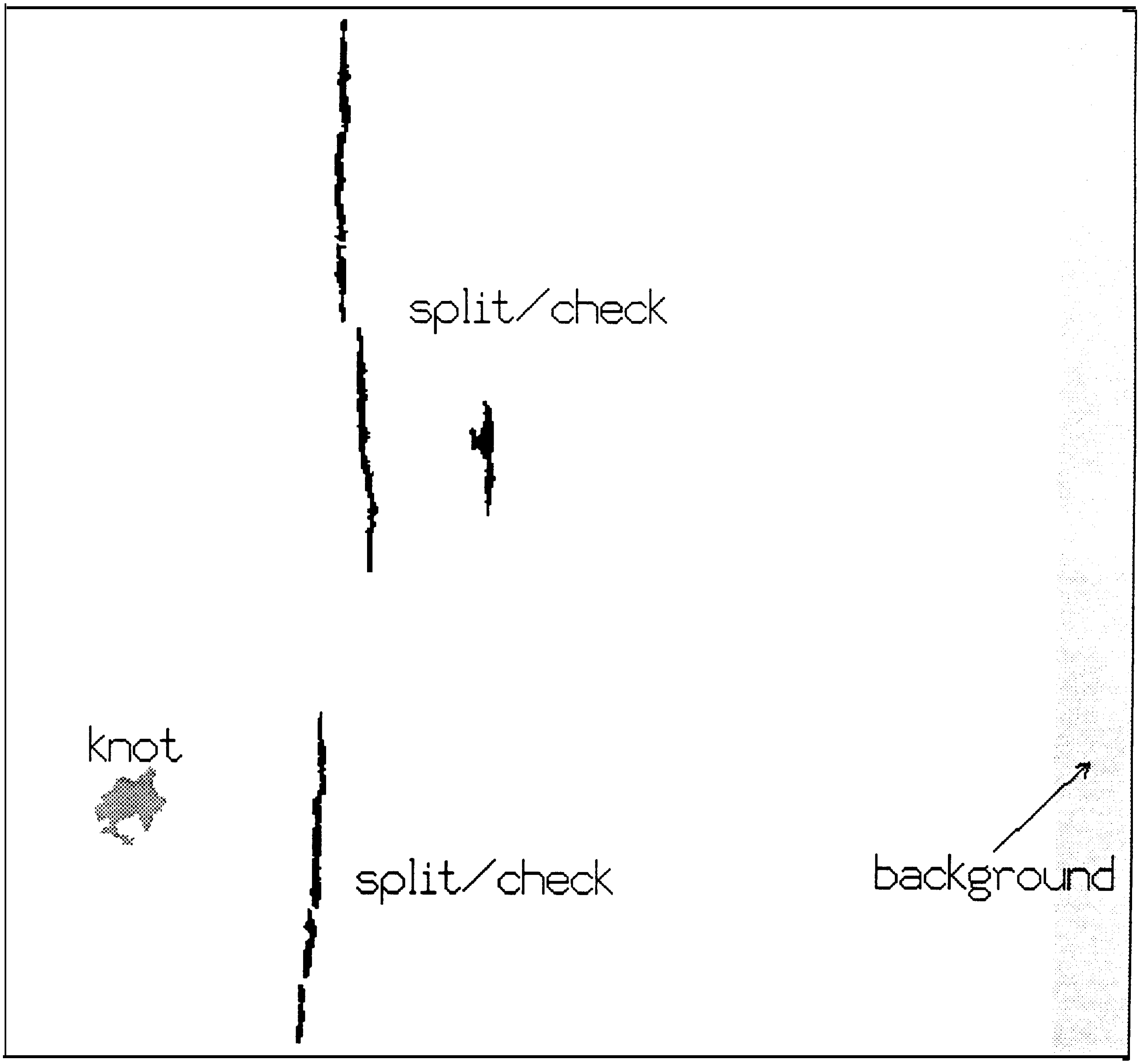

Figure 4. Machine recognizable features in the image of Figure 3.

of spatial resolution and still be able to maintain enough information to select an appropriate edging and trimming solution. For example, 16 pixels per inch by 32 pixels per inch for length and width, respectively, will reduce the amount of data that must be processed to about 1 megabyte per second. A second method is to determine which board features contribute the most to proper edging and trimming solutions. For example, if wane information is enough to make useful edging and trimming decisions, then, algorithms can be developed to identify regions of wane and discard all other information. A third method is to use a series of scanning sensors, each of which are optimized to identify particular features. For example, a laser scanning sensor can be used in combination with the vision system. The laser scanner can be used to quickly identify board profile information such as thickness, length, width, and wane. The vision system algorithms then need only to locate and identify features within the boundaries defined by the laser scanner. Current research is underway to determine the marginal value of greater resolutions and known feature information to the optimality of the edging and trimming solution.

Optimal Edging and Trimming Solution

After processing board images to locate and identify those features that affect hardwood edging and trimming value, some type of procedure is needed to determine the placement of the sawlines that establishes maximum lumber value. Since there are an infinite number of ways to edge and trim a board, a heuristic procedure was developed to converge upon the true optimal edging and trimming solution (Regalado, 1990). The edging and trimming program accepts data in the form of rectangular coordinates enclosing the periphery of a feature. The board image processing component can be easily adapted to provide data in this form. The optimization procedure uses hardwood lumber grading rules and prevalent market prices to determine lumber value. That is, a number of potential edging and trimming solutions are generated and each solution is graded and assigned a value according to the market price. The one solution that yields the maximum value is the optimum edging and trimming solution.

The optimization procedure incorporated a computer program to grade boards based on National Hardwood Lumber Association (NHLA) rules (Klinkhachorn et al., 1988). The grading program was used to determine the board grade and surface measure (i.e. surface area of the board) for each edging and trimming solution generated in the optimization procedure. Again, the processing speed of the grading program and the optimization procedure must all occur in a reasonable amount of time so that the total decision-making component can be accomplished within the desired board throughput rate. Although the speed of microprocessors is steadily increasing, the computational complexity of the decision-making component must be such that relatively inexpensive computing hardware can be used.

Mechanical Component

The effectiveness of an automated edging and trimming system will also depend on the ability of each machine center to accurately execute the optimum solution determined by the decision-making component. Current hydraulic linear positioners and stepping motors that are used in lumber manufacturing have the speed, power, and precision necessary to accurately execute the optimal edging and trimming solution. Programmable logic controllers (PLC) have found a wide application in lumber manufacturing as an interface between the computer and the machine center. The PLC, for example, receives instructions from the computer that processes the board image information and then translates them into commands that can control the edger and trimmer.

An automated edging and trimming system must be able to handle at least the same volume of material as the manual mill operation it is to replace. For a typical hardwood sawmill, this means feed rates for edgers must be about 10 to 15 boards per minute and between 30 to 60 pieces per minute for trim saws. The size of the board must also be considered in the design of an automated system. Although an average board may be about 8 inches wide and 13 feet long, there exist boards over 20 inches wide and 16 feet long. Board thickness typically varies between 1 inch to sometimes over 2 inches.

The success of the automated system also depends on a materials handling system to move the required volume of material from the scanning component to the edger and then to the trim saws. True edging and trimming optimization cannot be achieved by optimizing edging independently of trimming. It is therefore ideal to have these two operations within one integrated optimizing system. In such an integrated system, the materials handling system must be able to maintain a precise board orientation and sequence so that the edging and trimming solution is performed correctly on the appropriate board. Such precise control in a materials handling system may cost more than a computer vision system. The complexity of the materials handling system may be simplified by marking trimming instructions on edged boards or by using a separate scanning system for the trim saw. In any case, the overall system design must consider the material handling requirements.

ANTICIPATED BENEFIT

The goal of any automation activity must be to offset the investment in equipment by any benefits derived through reducing processing costs and increasing value. Given that most hardwood sawmills in the Southeast are not heavily capitalized, the benefit to cost ratio for an automated edging and trimming system is of primary concern. Therefore, the potential benefits must be established.

Figure 5 compares observed lumber values obtained at three different sawmills in southwest Virginia to the optimized edging and trimming value. The optimal values were determined by executing a computer optimization procedure on unedged and untrimmed board images (Regalado, 1990). Observed lumber values were determined by recording how the actual boards were processed in each of the mills studied. It was concluded that the mills studied had the potential of increasing their final lumber value by at least 20 percent through optimal edging and trimming. Two of the three mills studied had the potential of increasing lumber value by at least 35 percent. Translating these percentages into dollars, if the current average value of lumber produced is priced at 50 cents per board foot and one million board feet goes through both the edging and trimming process annually, the potential gain in lumber value alone can be as high as $175,000 per year for each mill.

Realizing that an overall integrated edging and trimming system may be overly complex and costly, it is of interest to optimize edging and trimming independently from each other. Table 1 compares the percent value gains for optimal edging and trimming, to optimal edging and manual trimming, and to manual edging and optimal trimming. Since edging an trimming operations are not totally independent, the percent improvement associated with optimal edging only and optimal trimming only do not necessarily add up to the percent improvement due to optimal edging and trimming. If selecting between optimized edging or optimized trimming, Table 1 would indicate that an automated edging system would be a better investment. However, recall that the trim saw receives material from the resaw as well and the volume of material handled at the trimmer can be as high as five times the volume handled at the edger. Therefore, an automated trimming system may be an equally attractive investment.

The potential benefits described above assume that all board information important in determining grade can be provided by a board scanning system. The benefit will be reduced if not all information can be sensed. As noted previously, the board scanning system must be able to at least sense board geometry information. Table 1 also shows the

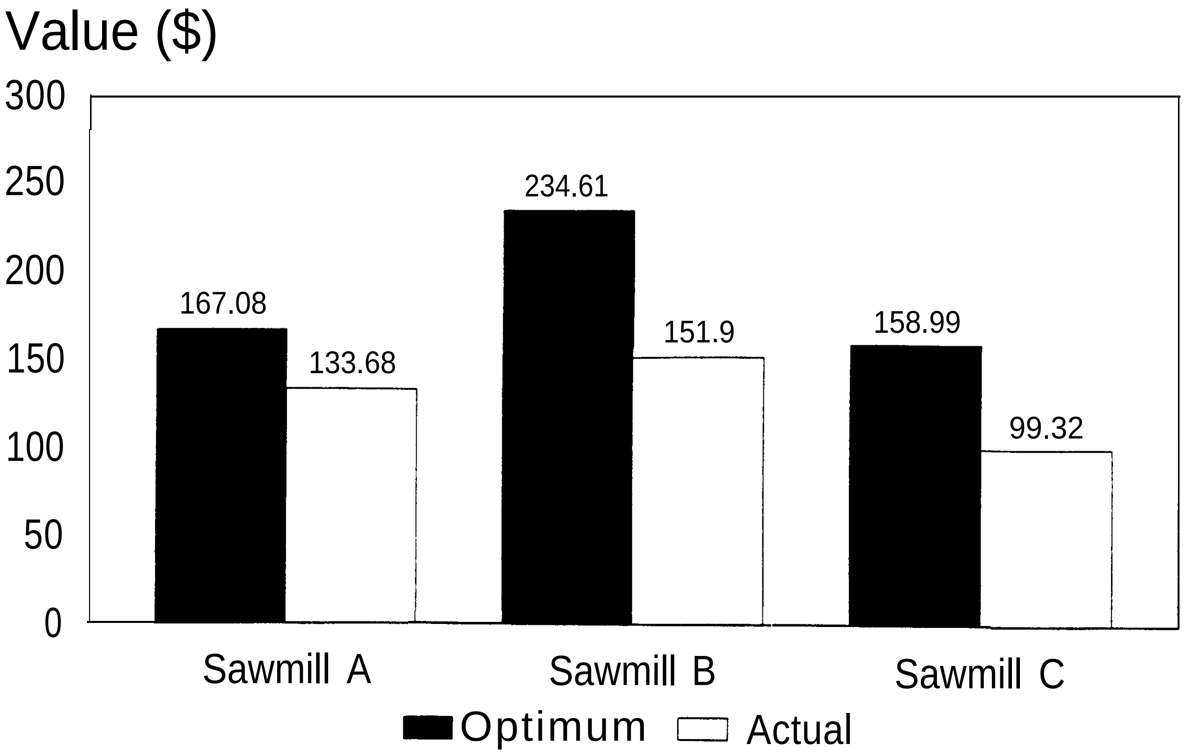

Figure 5. Comparison of optimal lumber value to observed.

Table 1. Comparison percent gain in lumber value for various levels of optimization

Optimization Level	Sawmill A	Sawmill B	Sawmill C
Edging and Trimming	20%	35%	37%
Edging only	12%	32%	33%
Trimming only	11%	9%	4%
Wane-based Edging and Trimming	2%	23%	16%

percent of optimal edging and trimming improvement over actual given only geometry information (i.e. length, width, and wane). Given only geometry information, substantial value increases of up to 23 percent can still be realized while reducing the complexity of the board scanning system. A study is in progress to determine the sensitivity of percent improvement for various combinations of board features.

PROGRESS AND FUTURE PLANS

Research activity has progressed in three primary areas. As detailed above, the first area involves establishing the potential benefit of an automated hardwood edging and trimming system. Establishing the benefit of the system is needed to determine the maximum cost of the automation equipment that can be justified by the hardwood lumber manufacturing industry.

The second area has concentrated on more precisely defining the accuracy requirements and performance parameters for the machine vision system. This area addresses how well and at what cost can board information be recognized by the system. Significant progress has been made in developing a full scale prototype materials handling system that can handle full sized lumber at industrial speeds (Conners et al., 1990). The purpose of the materials handling system is to mount various imaging components and evaluate their performance in scanning certain board features. The vision system will also be used to record many high resolution board images to further augment the results in potential benefit. Results from the first two areas of activity will be used to select a cost-effective design that will best suit the industry's needs.

As the research in this second area expands, the ultimate edging and trimming system will be totally operated by the computer. However, it should be realized that most hardwood sawmills are very small and may never be able to adopt a totally automated system. Therefore, the third area of activity has been involved in developing a computer-aided processing system to assist edging and trimming operators. This system will display board images on a computer monitor simulating an edging and trimming system. The operator would then position the saw kerfs on the monitor and the computer would give some performance feedback to the operator before an actual edging or trimming decision is made. The computer-aided edging and trimming system w-ill ultimately evolve into the full-scale automated system while assisting operators in making proper edging and trimming decisions in the meantime.

CONCLUSIONS

Over the last few years significant progress has been made on developing an automated edging and trimming system for hardwood lumber. Preliminary results have shown that a typical hardwood sawmill can increase their lumber value by as much as $175,000 per year by optimizing their edging and trimming operations. These results indicate a substantial value increase and merit the development of a technology to achieve optimal hardwood edging and trimming.

Capturing most of this potential value depends on a computer vision technology that is robust enough to handle all hardwood features that are important in establishing hardwood lumber value. The cost of the system depends on the many different components needed to successfully support and implement the computer vision technology. Work is continuing to find out how much of the potential value can be captured and at what cost.

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