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LUMBER SCANNING SYSTEM FOR SURFACE DEFECT DETECTION

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SUMMARY:

This paper describes research aimed at developing a machine vision technology to drive automated processes in the hardwood forest products manufacturing industry. An industrial-scale machine vision system has been designed to scan variable-size hardwood lumber for detecting important features that influence the grade and value of lumber such as knots, holes, wane, stain, checks, and splits. The system has also been designed to be general purpose so that a variety of different industrial-scale problems in the hardwood forest products manufacturing industry can be addressed.

KEYWORDS:

COMPUTER VISION, AUTOMATION, HARDWOOD LUMBER MANUFACTURING

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ABSTRACT

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 their wood raw material. Lumber production is 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 lumber manufacturing must involve some degree of automation. This paper describes research aimed at developing a machine vision technology to drive automated processes in the hardwood forest products manufacturing industry. A prototype machine vision system has been designed to scan variable-size hardwood lumber for detecting features such as knots, holes, wane, stain, checks, and splits. The prototype system has also been designed to be general purpose so that a variety of different problems can be addressed in both primary and secondary hardwood manufacturing.

INTRODUCTION

Hardwood lumber manufacturers in the eastern U.S. produce more than 10 billion board feet (24,000 m^3) of sawn hardwood lumber annually (Araman et al., 1992). Present trends such as increasing costs and limited supplies of high quality timber resources, have been making hardwood lumber manufacturers increase efforts to look for new ways to reduce costs and increase product value recovery. Presently, hardwood lumber production is less than optimum because of the complexity of the grading rules, the decision process,

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operator skill, operator fatigue, and the precision of available mechanical setworks. The optimization of a lumber manufacturing system must involve some type of automation technology to sense important hardwood features, make correct processing decisions, and then control downstream processing equipment with minimal operator intervention.

Developing such an automation technology is not an easy task. Wood is the perhaps the most heterogeneous of all the raw materials used in any manufacturing process. The appearance of wood varies significantly both within and between species. An automated lumber manufacturing system must be able to reliably detect many hardwood lumber features such as geometry, wane, knots, splits, holes, stain, and decay, Automatic detection of these randomly occurring features in such a heterogeneous material is a very unique and complex task.

Since the early 1980's, research has been conducted on developing a machine vision technology for automation applications in the hardwood forest products manufacturing industry. This research has led to significant developments in hardware and software for detecting important features in wood that affect its quality. In the past, the application of machine vision in hardwood manufacturing was limited because the needed computational power was either unavailable or too costly. However, with recent advances made by the computer industry and future projected advances, real-time applications in process automation utilizing the machine vision technology is becoming much more promising.

Over the last few years, research aimed at developing a general purpose machine vision technology for the forest products manufacturing industry has been conducted at Virginia Tech. Significant progress has been made in creating an industrial scale machine vision system for solving a number of wood products processing problems. All components of the system including color based cameras and laser based ranging cameras have been designed and built (Conners et al., 1990a; Conners et al. 1990b). Such a system is unique in that it can handle full-sized lumber at industrial speeds. Hence, industrial scale problems can be investigated. The system is being used to address a number of manufacturing problems including automatic edging and trimming, automatic lumber grading, and rough mill automation (Araman et al., 1992; Conners et al., 1992). This paper reports the progress that has been made on developing the industrial scale machine vision system.

BACKGROUND

The typical components for hardwood lumber sawmill include a debarker, a headrig, an edger, a resaw, and a trimmer (Figure 1). Actual mill layouts can vary substantially depending on the size and goals of the sawmill. In general, logs enter a 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.

Ideally, achieving the maximum potential hardwood lumber value would involve detecting all important internal log defects before the log is sawn, determining the best breakdown of the log that achieves the highest value lumber, and then controlling and integrating all sawmill components described in Figure 1 to achieve the highest value lumber. Although research in machine vision systems for identifying internal defects in logs is being explored (Araman et al., 1992), such an integrated sawmill system is presently in the conceptual stages.

A more practical approach to introducing machine vision systems in a sawmill would involve automating a few of the components that have the most effect on lumber value recovery. For example, automating the edging and trimming operations can be one area that can substantially increase lumber value recovery (Regalado et al., 1992). Consistent high-quality lumber and accurate grades are extremely important factors in customer satisfaction (Bush et al., 1990). Hence, another example would involve the automation of the lumber grading and sorting phases to more accurately control lumber quality.

With the falling prices of "high speed" computers and other supporting hardware and software for machine vision applications, hardwood lumber manufacturers are looking seriously at computer automated technologies for increasing lumber production efficiency. Such automated technologies will depend on a computer vision system for automatically detecting features that have the most effect on hardwood lumber value. Substantial progress has been made in developing the segmentation and recognition algorithms on color imagery for locating and identifying defects in rough hardwood lumber (Comers et al., 1992). These algorithms have been found to work equally well for a number of species including red oak, white oak, cherry, maple, walnut, poplar, hickory, and white pine. The recognition algorithms are currently developed to identify splits/checks, knots, holes, and wane. Work is continuing to further develop these algorithms to recognize other hardwood defects.

Based on the results that have been obtained to date (Comers et al., 1992), it is very difficult to accurately locate and identify all defects of typical rough lumber using only color image data, regardless of the computational complexity of the algorithms employed. For example, knots can be the same color as clear wood. Hence, it is possible for a defect such as a knot to be mis-classified as clear wood. Current evidence suggests that a significant improvement in real-time defect detection and recognition accuracies can be obtained if a variety of different sensors are used together. By integrating information from color cameras and other sensors such as an x-ray scanning system to aid in knot detection and laser based ranging camera systems for measuring board profiles, the accuracy and speed of the lumber scanning system will be such that a variety of lumber manufacturing automation applications can be addressed. However, much experimentation is required to develop and integrate these sensing technologies.

Currently, an industrial-scale machine vision system has been developed so that a variety of research experiments can be performed. To develop accurate and robust computer vision algorithms that utilize information from a variety of different sensors, the machine vision system must be able to handle full length lumber at industrial speeds. Also, the system must be flexible enough so that many different experimental procedures can be performed to validate the accuracy of lumber defect detection under conditions that are typically encountered in a hardwood sawmill environment.

MACHINE VISION SYSTEM DEVELOPMENT

To be able to research a number of problems associated with hardwood lumber manufacturing, the machine vision system must be general purpose and versatile. Therefore, the vision system must be able to identify most of the common features that effect the value of lumber. Common features include knots, holes, wane, stain, mineral streak, decay, splits, checks, and geometry. The hardwood species the system should be able to handle include white oak, red oak, walnut, cherry, maple, mahogany, yellow poplar, hickory, and ash. There is a significant variation in both color and grain pattern among these species. Furthermore, the surface of hardwood lumber is rough and comes in random widths and lengths. Developing general purpose computer vision methods for locating and identifying defects on such heterogeneous material is a difficult problem. Therefore, the specific design parameters of the sensing technology and supporting hardware and software subsystems must provide a great deal of flexibility.

The vast majority of hardwood lumber has widths less than 20 (50.8 cm) inches. Hardwood lumber comes in a variety of lengths, with the maximum length being around 17 feet (5.2 m). Lumber thickness ranges from 3/4 inches (1.9 cm) to slightly over two inches (5.1 cm). The typical lumber flow rate at a hardwood sawmill can range from 2 to 4 linear feet per second (0.61 to 1.22 m/s). Therefore, the machine vision system must be able to handle lumber Up to 17 feet (5.2 m), up to 20 inches (50.8 cm) wide, and Up to 2 1/4 inches (5.7 cm) and operate at industrial speeds of up to 4 linear feet per second (1.22 m/s).

As mentioned earlier, to achieve the desired level of accuracy in locating and identifying defects in lumber, a multisensory machine vision system will be required. Color image sensors alone will not adequately identify all defects on all hardwood species (Conners et al., 1992). Laser based ranging cameras will be needed to aid in the detection and recognition of a number of defects such as wane, holes, and splits. An x-ray scanner will markedly aid in both the detection and recognition of knots and decay. The integration of all of these imaging systems will be needed to create a truly robust and general purpose machine vision technology.

The overall machine vision technology for scanning hardwood lumber, therefore, can be conceptualized as many integrated systems (Figure 2). These systems include 1) the color imaging system, 2) the laser-based ranging system, 3) the X-ray scanning system, 4) the lumber handling system, 5) the image processing and system control computers, and 6) the image processing and application software.

Color Imaging System

The color imaging system uses color line scan camera technology. The line scan camera has a resolution of 864 color pixels. At present, the camera system is set up for a 13 1/2 inch (34.3 cm) field of view which is wide enough to handle the vast majority of lumber test specimens. The camera can run at 2.5 MHz. At this speed, the camera can generate images with 64 points per inch (25 points per cm) cross board resolution and 32 points per inch (12 points per cm) down-board resolution at board speeds of two linear feet per second (0.61 m/s). Tests indicate that this is more than enough resolution for hardwood lumber manufacturing applications and some resolution can be sacrificed if wider lumber at faster speeds need to be considered. Two of these cameras are being used, one for scanning each of the two board faces.

Light sources for illuminating board surfaces use tungsten-halogen incandescent bulbs. The light from a bulb is transferred to the board surface through a fiber-optic cable that is composed of a number of very thin fiber-optic light lines. At the opposite end of this cable, the fiber-optic lines are stacked on top of one another with their ends forming a straight line. The advantage of these fiber-optic lines is that the light sources can be quickly replaced when a bulb burns out, without physically disturbing the color imaging configuration.

A high-speed interface for the Microchannel bus has been designed and built that provides the mechanism for collecting the color imagery from both color cameras and storing it into computer memory (Drayer, 1991). This interface allows for the collection of color imagery data as fast as it can be generated by the camera systems at 2.5 MHz.

Laser Based Ranging System

The laser based ranging system uses a 128 x 128 pixel array camera and is presently set up for a field of view of 4 inches (10.2 cm). The camera can scan 384 frames per second. At this speed, the camera can generate range data with 32 points per inch (12 points per cm) cross board resolution and 16 points per inch (6 points per cm) down-board resolution at board speeds of two linear feet per second (0.61 m/s). The system can detect board thicknesses to within 0.01 inches (0.25 mm). Future plans include integrating four of these cameras together, two cameras for seaming each of the two board faces. Although this four-camera system will be initially limited to an 8 inch (20.3 cm) field of view, it will be sufficient to determine whether additional cameras will be needed (as opposed to decreasing the cross board resolution with the existing cameras) to accommodate wider lumber.

The laser light source is generated with a 16mW Helium Neon gas laser at a 632.8 nm wavelength. A 24-facet polygon scan mirror rotating at approximately 30,000 RPM is used to sweep the laser light across a lumber specimen. As the laser light beam is emitted, it hits the rotating polygon mirror and is reflected onto the lumber The fast rotating mirror enables the laser light to sweep across the width of the specimen several times in one video frame period, creating the effect of a plane of laser light.

A dedicated high speed computer interface similar to the one for the color imagery data has been developed for the Microchannel bus. Image processing software algorithms are currently under development to efficiently interpret the laser-based range data.

X-Ray Scanning System

An additional scanner that is presently being considered for use on the machine vision system is an X-ray scanner. The scanner under consideration is similar to, but has a higher spatial resolution than, the X-ray seamers used to scan luggage at airports. This scanner has a 20 pixel per inch (7.9 pixel per cm) cross board resolution and will allow a 10 pixel per inch (3.9 pixel per inch) down board resolution at 2 linear feet per second (0.61 m/s). The development of this scanning technology will involve mounting the X-ray unit onto the lumber handling system, developing a high-speed interface similar to the one for the color imagery data, and development of the computer vision software algorithms to interpret the data.

Lumber Handling System

The lumber handling system was designed to handle full-sized hardwood lumber. The maximum dimension of each piece of lumber to be handled is 17 feet (5.2 m) in length, 20 inches (50.8 cm) wide, and up to 2 1/4 inches (5.7 cm) thick. The systems has programmable speeds ranging from 0 to 6 linear feet per second (1.8 m/s). The accuracy of the speed through the system is ± 1/100 of an inch (0.25 mm). The design of the lumber handling system provides space for seven imaging stations (Figure 3). These imaging stations are the positions where the color cameras, laser-based range cameras, and X-ray scanner will be located.

Image Processing and System Control Computers

At the spatial resolutions currently being used for color imagery data alone, a hardwood board 16 feet (4.9 m) long will generate 32 megabytes of data from both sides of the board. At industrial speeds this data must be collected and processed in 4 to 8 seconds. The x-ray and laser-based imaging systems, when fully integrated, will add even more data to this total. An IBM RS/6000 520 series workstation is being initially used as the image processing computer. Although the RS/6000 does not process the image data at the required industrial speeds, it is adequate to provide a reasonable turnaround for research purposes. However, the image processing subsystem has been designed in such a way that it can effectively use a multiple instruction stream, multiple data stream (MIMD) computer architecture. Hence, by the time the imaging systems are fully developed and integrated, the necessary high-speed computers with MIMD architecture should be available at a very reasonable cost.

The system control computer uses an IBM PS/2 computer. The purpose of the control computer is to provide control signals to the lumber handling system and to the image processing computer. This computer will continuously monitor many system components to assure they are working properly. An important consideration in developing the control software is to create an interface that will allow a typical employee of a sawmill to operate the machine vision system and perform routine maintenance.

Image Processing and Application Software

Once all image data are collected from the imaging systems described above, the image must be interpreted. Image interpretation consists of two tasks: image segmentation and object recognition. Segmentation distinguishes and separates aspects of the scene that are of interest. In the analysis of hardwood lumber, the goal of the segmentation task is to separate areas of clear wood from potential areas of defect. Recognition on the other hand, requires technical knowledge of wood features and patterns to identify defects that affect the value of lumber. A knowledge-based system using a blackboard architecture has been used successfully in locating and identifying defects using color imagery data (Cho, 1991). Work is continuing to expand this knowledge-based approach to help integrate the multiple sources of information that will be simultaneously collected from the various sensors.

To demonstrate the utility of the machine vision system, application software has been developed to use the results of the image processing software. Presently, several applications have been developed: (1) a hardwood lumber edger and trimmer simulator (Kline et al., 1992), (2) a hardwood lumber grading program (Klinkhachorn et al., 1988), and (3) hardwood lumber cut-up program. The hardwood lumber edger and trimmer simulator can take the results of the image processing software and graphically display the board along with the edger and trimmer saw kerfs. The computer can automatically position the edger and trimmer sawlines for maximum lumber value. A hardwood lumber grading program can also be used to automatically grade the hardwood lumber processed through the machine vision system. The hardwood lumber strips cut-up program simulates cutting narrow fixed-width boards to user-specified lengths to maximize volume recovery. This cut-up program is used to study the potential for manufacturing dimension products from lumber. Although this cut-up program is specialized for narrow fixed-width boards, other existing programs such as CORY (Brunner et al., 1989) can be implemented to cut full-sized lumber into dimension. In addition to demonstration purposes, the edger and trimmer simulator, grading program, and lumber cut-up programs are being used to evaluate the accuracy and performance of the machine vision system.

CONCLUSION

Much progress has been made on developing a general purpose machine vision technology for the hardwood lumber manufacturing industry. The development of color imaging systems, laser-based ranging systems, interface hardware, computer algorithms, and the full-scale lumber handling system have all been designed and built. The addition of an X-ray scanner along with the total integration of all machine vision system components is the key to future progress. The full integration of all of these imaging systems will markedly speed the development process allowing the creation of a truly flexible and robust machine vision technology with the next few years. Such a technology will allow for the thorough investigation of industrial-scale lumber manufacturing problems that have previously been impossible.

REFERENCES

Araman, P. A., D. L. Schmoldt, T. H. Cho, D. Zhu, R. W. Conners, and D. E. Kline. 1992. Machine vision systems for processing hardwood lumber and logs. AI Applications 6(2):13-26.

Brunner, C. C., M. S. White, F. M. Lamb, and J. G. Schroeder. 1989. CORY: a computer program for determining dimension stock yields. Forest Products Journal 39(2):23-24.

Bush, R, J., S. A. Sinclair, and P. A. Araman. 1990. Matching your hardwood lumber to market needs. Southern Lumberman 251(8):24-27.

Cho, T. H. 1991. A knowledge-based machine vision system for automated industrial web inspection. Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Conners, R. W., C. T. Ng, T. H. Drayer, J. G. Tront, and D. E. Kline. 1990a. Computer vision hardware system for automating rough mills of furniture plants. Proceedings of the SPIE, Applications of Artificial Intelligence, VIII, Orlando, Florida, pp. 777-787.

Conners, R. W., T. H. Cho, C. T. Ng, T. H. Drayer, P. A. Araman, and R. L. Brisbin. 1990b. A multisensory machine vision system for hardwood defect detection. Proceedings, Process Control/ Production Management of Wood Products: Technology for the 90's, Athens, Georgia, pp. 99-110.

Conners, R. W., T. H. Cho, C. T. Ng, T. H. Drayer, P. A. Araman, and R. L. Brisbin. 1992. A machine vision system for automatically grading hardwood lumber. Industrial Metrology 2:317-342.

Drayer, T. H. 1991. A high performance microchannel interface for image processing applications. Masters Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Kline, D. E., E. M. Wengert, P. A. Araman, and P. Klinkhachorn. 1992. Hardwood lumber edger and trimmer training system. Forest Products Journal 42(1):53-57.

Klinkhachorn, P., R. W. Conners, and H. A, Huber. 1988. Automated computer grading of hardwood lumber. Forest Products Journal 38(3):67-69.

Regalado, C., D. E. Kline, and P. A. Araman. 1992. Value of defect information for automated edger and trimmer systems. Forest Products Journal 4(3):29-34.

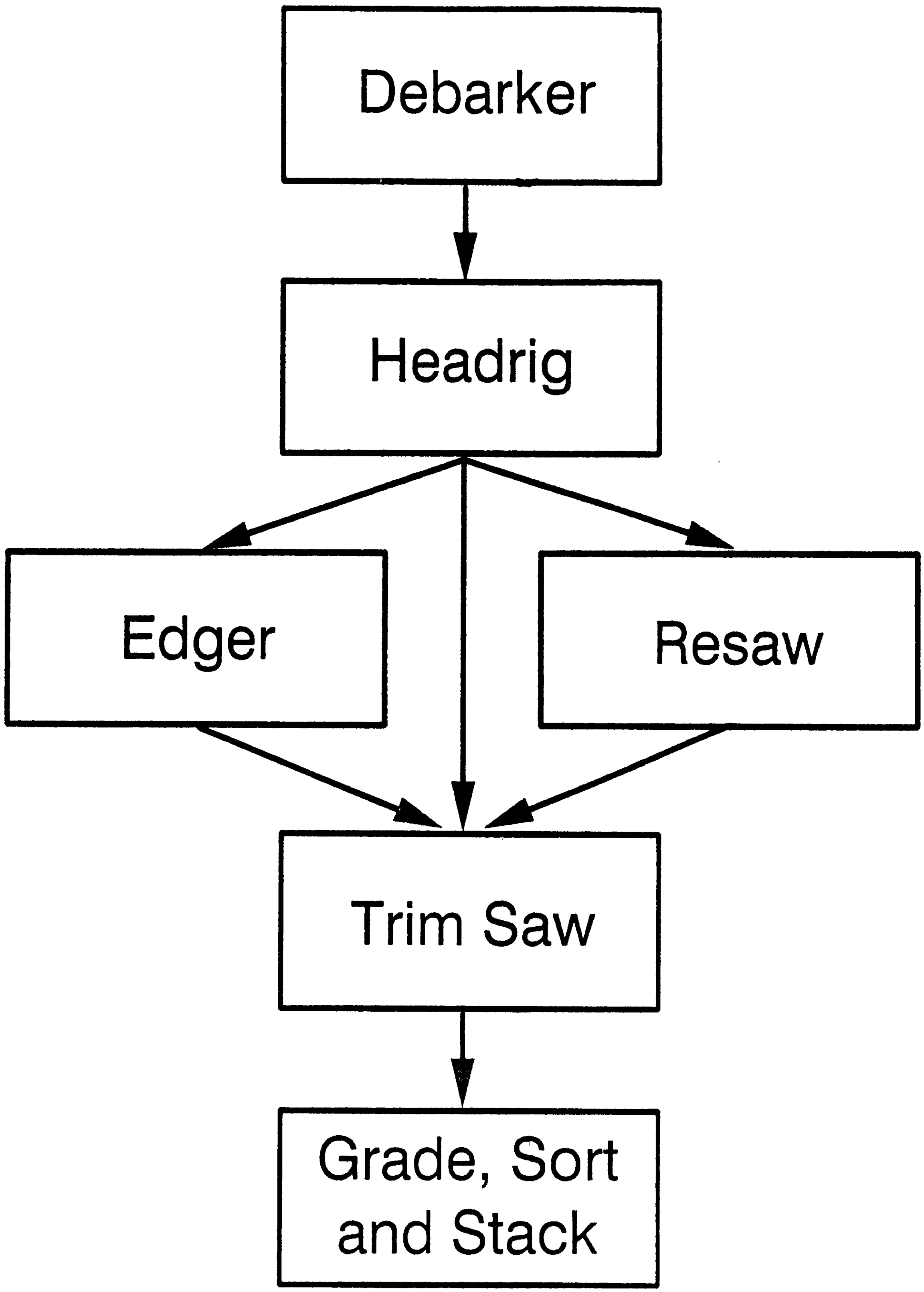

Figure 1. Basic components of a hardwood sawmill.

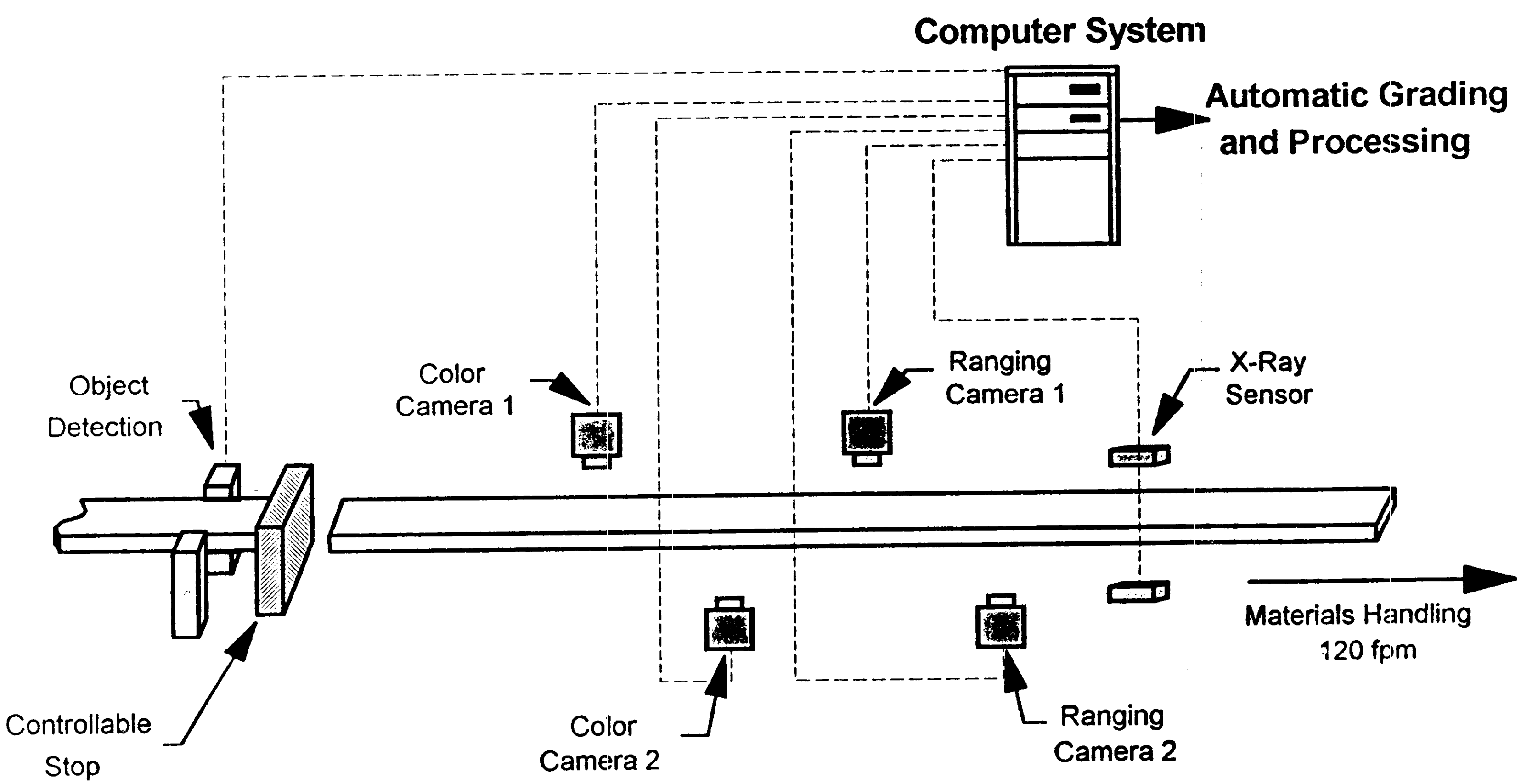

Figure 2. Conceptualization of the machine vision system.

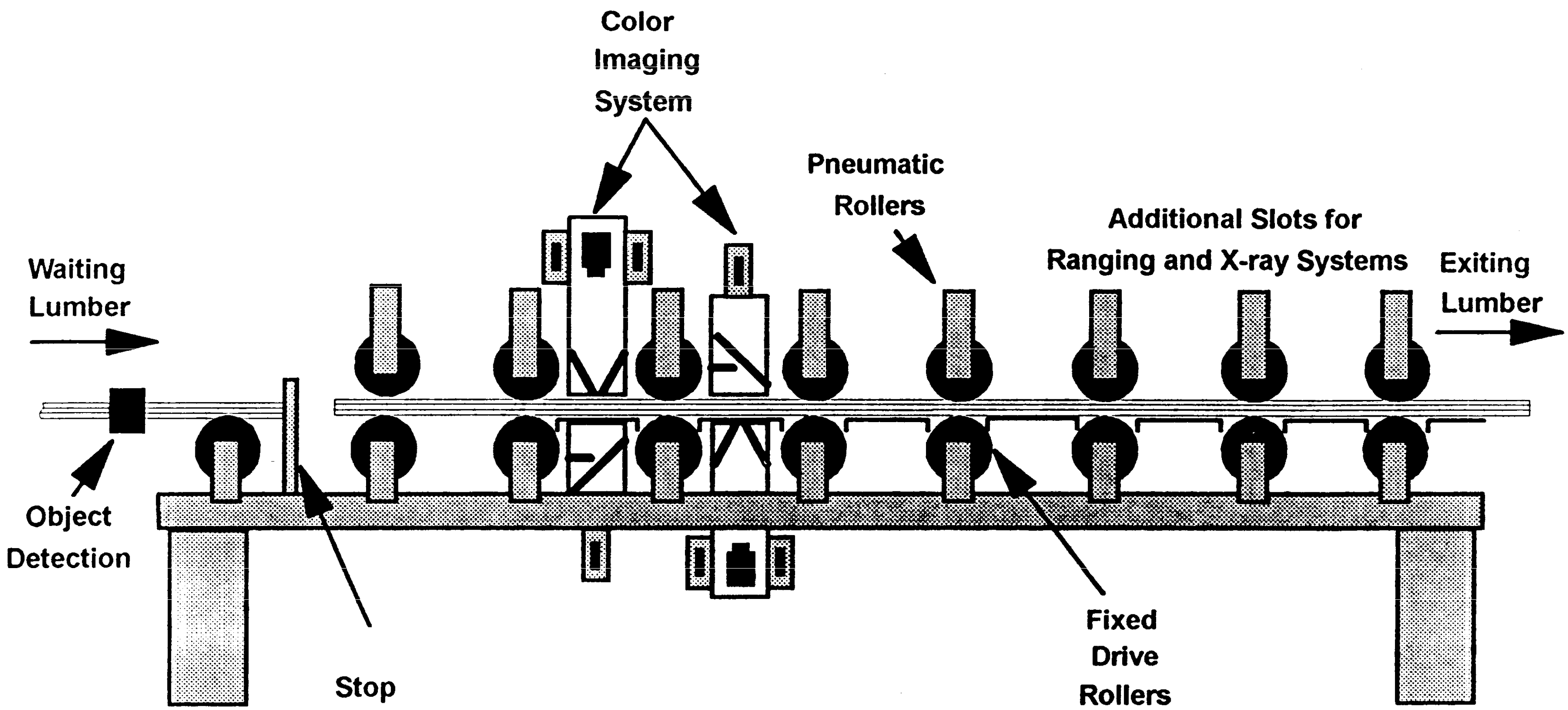

Figure 3. Conceptualization of the lumber handling system for the industrial scale machine vision system