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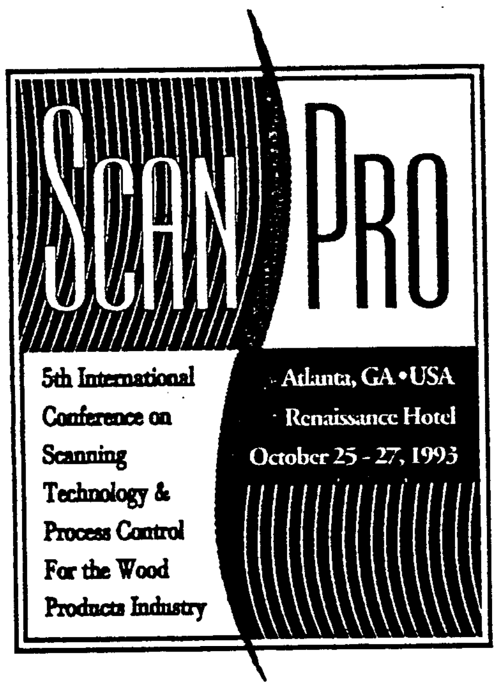

A MULTIPLE SENSOR MACHINE VISION SYSTEM FOR AUTOMATIC HARDWOOD FEATURE DETECTION

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ABSTRACT

A multiple sensor machine vision prototype is being developed to scan full size hardwood lumber at industrial speeds for automatically detecting features such as knots, holes, wane, stain, splits, checks, and color. The prototype integrates a multiple sensor imaging system, a materials handling system, a computer system, and application software. The prototype provides a unique general purpose research facility so that a variety of different industry-scale problems can be addressed in both primary and secondary hardwood manufacturing.

BACKGROUND

There are three main categories into which features on hardwood lumber may be classified. These are: 1) visual surface features (e.g. knots holes, splits, decay, color, grain orientation), 2) board geometry features (e.g., warp, crook, wane, thickness variations, voids), and 3) internal features (e.g., honeycomb, voids, decay). Surface geometric, and internal features have been categorized in this way because they often require different detection methods that depend on where they appear. Most of these features are treated as defects to be removed in the manufacturing process. Current hardwood mill operations examine lumber manually to locate and identify these types of defects.

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Installation of automated inspection systems, however, is becoming increasing] y important for hardwood processors to maintain profit margins and remain competitive. These systems promise the capability to accurately and consistently locate and identify lumber defects and therefore to help reduce waste and create high-quality products in subsequent mill processing. It is generally recognized that no single sensing modality can distinguish all categories of defects (Szymani and McDonald, 1981). The different sensors being applied to defect detection on lumber are: microwaves (King, 1978; Portala and Ciccotelli, 1990), capacitance sensors (McDonald and Bendtsen, 1986; Steele et al., 1991), x-ray imaging (Kenway, 1990; Portala and Ciccotelli, 1990), laser scanning, and optical Scanning (Conners et al., 1990; McMillin et al., 1984). Each of these sensing systems is adept at detecting certain kinds of defects and not others.

From a review of the above research efforts and those of Conners et al. (1992), it is readily apparent that multiple sensing systems are absolutely necessary for machine vision systems to be broadly useful for a variety of mill operations. For example, it is very difficult to accurately locate and identify all surface features on typical rough lumber using only color image data, regardless of the computational complexity of the algorithms employed. Knots can be the same color as clear wood, and hence may be misclassified as clear wood. By integrating information from color cameras and other sensors such as laser-based ranging camera systems and x-ray scanning sensors, the accuracy and speed of a lumber scanning system can address a variety of manufacturing automation applications.

Over the last few years, investigators at Virginia Tech have been conducting research aimed at developing a general purpose machine vision technology for the forest products manufacturing industry. Substantial progress has been made in developing the image processing algorithms for color imagery to locate and identify surface features on hardwood lumber (Cho, 1991). 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 have been developed to identify splits, checks, knots, holes, and wane. Work is continuing to further develop these algorithms to recognize other hardwood features.

The next step has been taken to create a multiple sensor machine vision prototype that can be used to research a number of wood products processing problems. In addition to the original color camera system, a laser-based ranging system and an x-ray scanner have been added. This prototype is clearly unique because several different sensing modalities can be tested on fill-sized lumber at industrial speeds. The prototype is being used to address a number of primary and secondary hardwood manufacturing problems including automatic sawmill edging and mumming, automatic lumber grading, automatic color sorting, 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 prototype.

MACHINE VISION SYSTEM DEVELOPMENT

To investigate a number of problems associated with hardwood products manufacturing, the machine vision system must be general purpose and versatile. Therefore, the vision system must be able to accurately identify most of the common features that effect the value of hardwood lumber and the quality of products that are produced when lumber is further processed. Common features include knots, holes, wane, stain, mineral streak, decay, splits, checks, color, grain, and geometry. Furthermore, a vision system must be able to handle most of the major hardwood species including white oak, red oak, walnut, cherry, maple, mahogany, yellow poplar, hickory, and ash. The system must be robust enough to deal with the wide range of variations in the way features manifest themselves both within and between these species. Also, any industrial machine vision system must be able to handle full-sized lumber at industrial speeds, where lumber can be either rough or surfaced. Lumber size varies in width (1-1/2” - 20”), in length (2’ - 17’), and in thickness (3/4” - 2-1/4”, and lumber moves through a mill at 120-240 feet/minute. Hence, the specific design parameters of the sensing technology and supporting hardware and software subsystems must provide a great deal of flexibility.

To achieve the demands of multiple-application accuracy and flexibility, a multiple sensor machine vision system is required. Currently, efforts are underway to explore three different sensing technologies: 1) color imaging sensors, 2) laser based ranging sensors, and 3) x-ray scanners. Color imaging sensors are obvious devices to identify features relating to light intensity variations in wood such as knots, stain, color, and grain pattern. Laser based ranging sensors can accurately detect a number of features related to the profile of the wood material such as wane, holes, splits, material thickness, and surface smoothness. An x-ray scanner will markedly aid in both the detection and recognition of features that have different densities such as knots, decay, and honeycomb. Because each of these different sensing systems provides a unique type of information about the nature of the wood material, research can be conducted as to which sensing technology or combination of sensing technologies are best suited for a particular industrial application.

The overall machine vision technology for scanning hardwood lumber, therefore, can be conceptualized as many integrated systems (Figure 1). These systems include 1) the color imaging system, 2) the laser-based ranging system, 3) the x-ray scanning system, 4) the material handling system, 5) computers for machine vision and system control, and 6) machine vision 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. Although the camera systems can be adjusted for different material widths, it is presently configured for a 13 1/2 inch field of view which has been wide enough to handle all of the lumber specimens tested to date. The camera has a scan rate of 2.5 MHz. At this configuration and scan rate, the camera can generate images with 64 points per inch cross board resolution and 32 points per inch down-board resolution at board speeds of 2 linear feet per second. Tests indicate that this is more than enough resolution for most hardwood processing applications. Two of these color imaging systems are being used, one for scanning each face of the board.

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 joined end to end forming a straight line. The advantage of these fiber-optic lines is that the light sources can be quickly replaced when a bulb bums out, without physically disturbing the color imaging configuration.

A high-speed interface based on the Microchannel bus architecture has been designed and built. This interface provides the mechanism for collecting the color imagery from both color cameras and storing it into computer memory. Color imagery data is stored into memory as fast as it can be generated by the camera systems.

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. The camera can scan 384 frames per second. At this speed, the camera can generate range data with 32 points per inch cross board resolution and 16 points per inch down-board resolution at board speeds of two linear feet per second. The system can detect board thicknesses to within 1/64 inches. Future plans include integrating eight of these cameras together, four cameras for scanning each of the two board faces. Although this 8 camera system will be initially limited to a 16 inch 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. 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 line of laser light. Based on trigonometry of the camera and laser setup, deflections of the laser line are used to calculate board profile variation. It is also possible to detect light intensity variation along the laser line.

A dedicated high speed computer interface similar to the one for the color imagery data has been developed for the Microchannel bus. The interface condenses each 128 x 128 video frame into two, 128-byte arrays, one containing 8-bit range data and the other 8-bit intensity (grey-level) data and stores them into computer memory. Machine vision algorithms are currently under development to efficiently interpret the laser scan data.

X-Ray Scanning System

The x-ray scanner is similar to, but has a higher spatial resolution than, the x-ray scanners used to scan luggage at airports. This scanner has a 20 pixel per inch cross board resolution and will allow a 10 pixel per inch down board resolution at 2 linear feet per second. Current work with this scanning technology involves mounting the x-ray unit onto the material handling system, developing a high-speed interface similar to the one for the color imaging and profile ranging systems, and creating machine vision algorithms to interpret the data.

Material Handling System

The material handling system is able to handle lumber of various sizes. Lumber moves through the system pinched between rollers from above and below. The lower rollers drive lumber through the various scanning bays while the upper pneumatic rollers hold it flat during transport. The system has programmable speeds ranging from 0 to 6 linear feet per second. The positioning accuracy of material passing through the system is ± 0.01 inches. The design of the material handling system provides space for seven imaging devices, four of which are occupied by the color imaging, laser ranging, and x-ray scanner systems (Figure 2). An IBM PS/2 computer controls all aspects of moving lumber through the system.

Computers for Machine Vision and for System Control

At the spatial resolutions currently being used for color imagery data alone, a hardwood board 16 feet 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. The prototype currently uses an IBM RS/6000 520 series workstation as the image processing computer. Although the RS/6000 does not process the image data at the required industrial speeds, it is intended to be general purpose while fast enough for research uses. Once a technology has been developed for a particular industrial application, the appropriate computer system along with any special purpose image processing hardware can then be selected to perform the necessary machine vision operations in real-time.

The system control computer uses an IBM PS/2 computer. The purpose of the control computer is to provide control signals to the material handling system and to the image processing computer. This computer will continuously monitor many system components to assure they are working properly. Current work in the development of the control software involves creating an interface that will allow a typical employee of a hardwood manufacturing plant to operate the machine vision system and perform routine maintenance.

Software for Machine Vision and for Mill Applications

Once all image data are collected from the imaging systems described above, machine vision software is utilized for image interpretation. Image interpretation consists of two tasks: image segmentation and object recognition. Segmentation distinguishes and separates features in the image 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 by type that affect the value and quality of lumber. A knowledge-based system using a blackboard architecture has been used successfully to locate and identify defects from 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 machine vision results for lumber processing operations. 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; Klinkhachorn et al., 1992), and 3) hardwood lumber cut-up program. The hardwood lumber edger and trimmer simulator can take the results of the machine vision 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. 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.

SUMMARY

The variety of hardwood lumber defects that must be detected by a machine vision system necessitates the use of multiple sensors. Much progress has been made on developing a prototype multiple-sensor machine vision technology for the hardwood products manufacturing industry. This prototype incorporates color imaging systems, laser-based ranging systems, an x-ray scanner, interface hardware, computer hardware and software, and a material handling system. Considerable work remains to be done to complete the installation of all scanning components and to integrate the scan data that are collected. Full integration of all of these imaging systems will markedly enhance the creation of a truly flexible and robust machine vision technology within the next few years. Such a technology will allow for the thorough investigation of industrial-scale wood products manufacturing problems that have not been possible previously.

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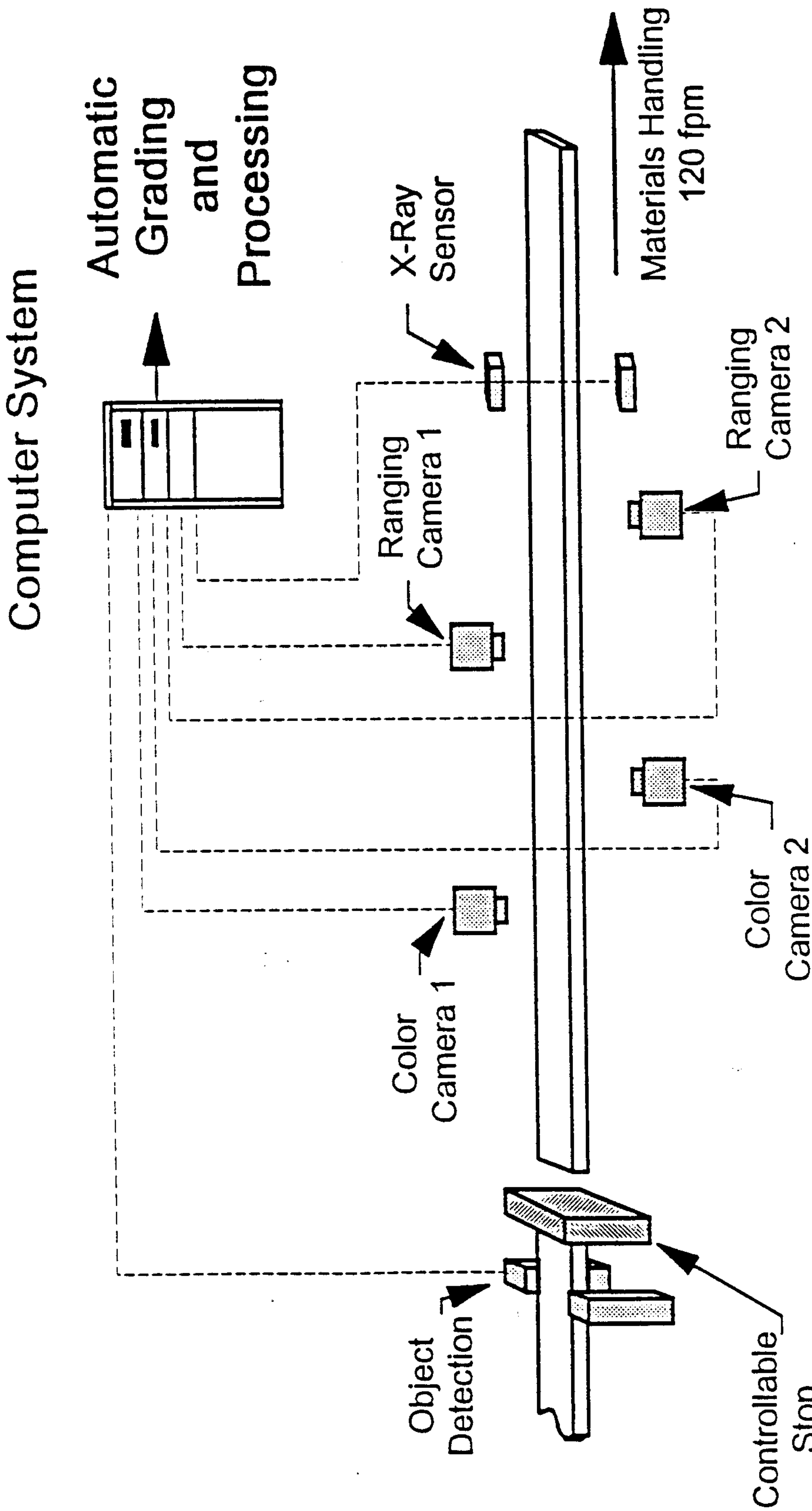
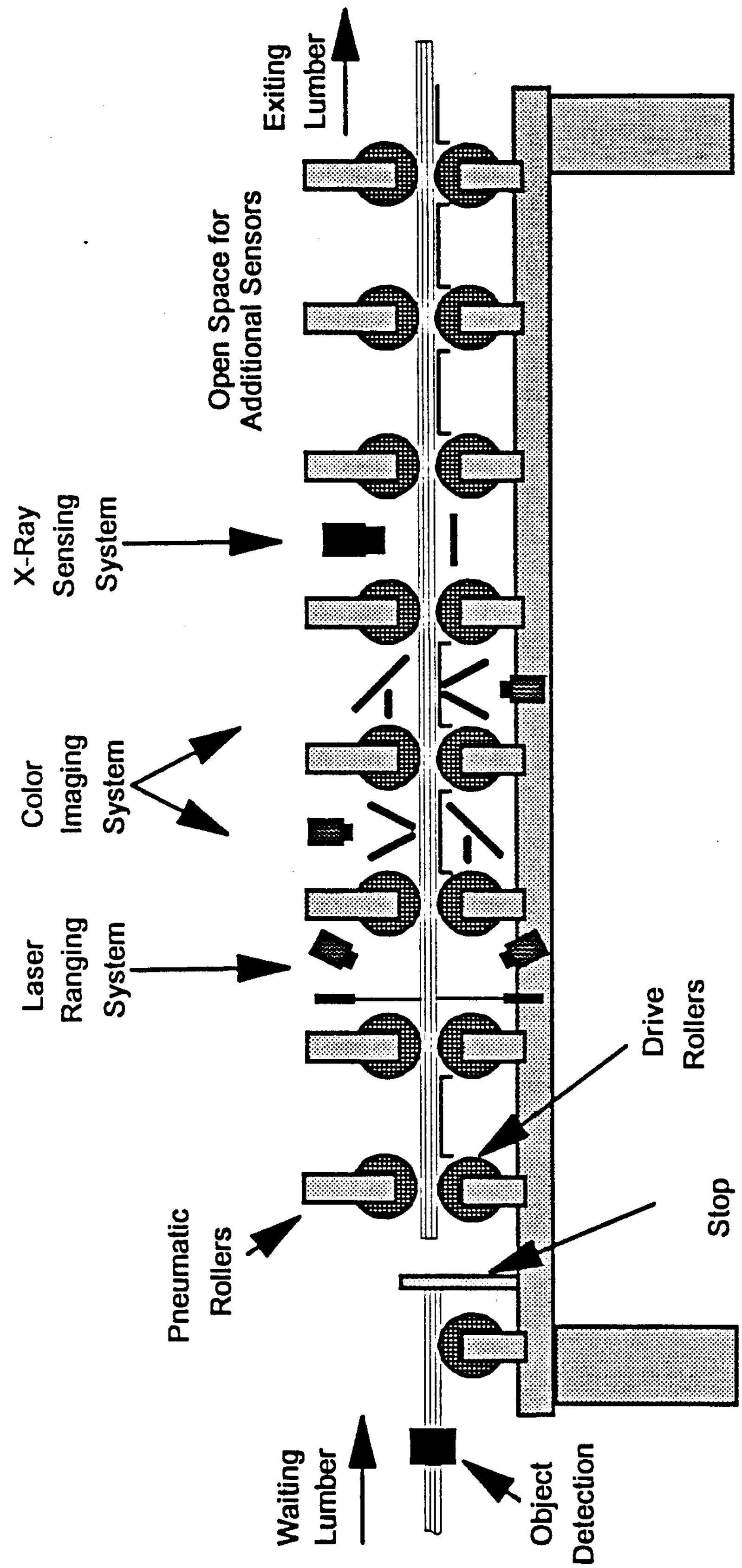


Computer System
Automatic Grading and Processing
X-Ray Sensor
Ranging Camera 1
Ranging Camera 2
Color Camera 1
Color Camera 2
Materials Handling 120 fpm
Object Detection
Controllable Stop


Exiting Lumber
Open Space for Additional Sensors
X-Ray Sensing System
Color Imaging System
Laser Ranging System
Drive Rollers
Stop
Pneumatic Rollers
Waiting Lumber
Object Detection