Computer Vision Hardware System for Automating Rough Mills of Furniture Plants

R. W. Conners*, C. T. Ng*, T. H. Drayer*, J. G. Tront*, D. E. Kline[@], and C. J. Gatchell[#]

*Spatial Data Analysis Laboratory, Virginia Tech, Blacksburg, VA 24061
[@]Forest Products Department, Virginia Tech Blacksburg, VA 24061
[#]Northeastern Forest Experiment Station, P.O. Box 152, Princeton, WV 24740

ABSTRACT

The rough mill of a hardwood furniture or fixture plant is the place where dried lumber is cut into the rough parts that will be used in the rest of the manufacturing process. Approximately a third of the cost of operating the rough mill is the cost of the raw material. Hence any increase in the number of rough parts produced from a given volume of raw material can markedly affect profit margins of a company. To automate this initial cutup requires a computer vision system that can locate and identify surface defects on boards. This paper describes continuing research aimed at developing such a vision system. An important part of this research activity is the design effort going into creating a prototype hardware system, a system that will be able to scan variable width,variable length hardwood boards at industrial speeds of two to three linear feet per second. This system is being designed to handle full length boards up to sixteen feet long. The components of the prototype are a materials handling system, an imaging system, a image processing hardware system, and a software system for performing the necessary recognition tasks and for performing all the necessary control functions. The design of each of these components will be described with the emphasis placed on hardware development.

1. INTRODUCTION

The rough mill of a furniture plant is the place where dried lumber is cut into the rough parts that will be used in the rest of the manufacturing process. Approximately a third of the cost of operating the rough mill is the. cost of the raw material. Hence any increase in the number of rough parts produced from a given volume of raw material will markedly affect profit margins.

To automate this initial cutup requires a computer vision system that can locate and identify surface defects on boards. The methods used in this vision system must be very robust. Because most furniture plants use a variety of different species, the vision system should be able to operate in a species independent manner without having an operator inform it of the species of lumber currently being processed.

Furniture and fixture manufacturing is a batch processing industry. That is, for some number of days, a table may be the only product produced. Then, overstuffed sofas may be produced at the plant over the next few days. The rough parts cut to make the frame of a sofa can have knots, even large knots, in them as long as the knots do not affect the structural strength of the parts. Parts cut to form the top of a hardwood table typically are not allowed to contain large knots and, depending on the quality of the product being produced, may not even be allowed to contain small knots. Hence the system must be such that it can be tailored by management to allow certain features in the rough parts that are acceptable and to remove other features when they are unacceptable.

This paper reports the progress that. has been made on creating such a vision system. The goal of this research is to have a commercially useful system by the end of 1992. Because of this deadline, work on four research topics is proceeding in parallel. These topics include algorithm/software development, imaging system development, materials handling system development, and image processing

hardware development.

This paper will concentrate primarily on the design of the hardware components of the vision s system. However, since the algorithms to be used affect system design some aspects of the software system will be described. For more information on the software system development see References 1 and 2.

2. SYSTEM REQUIREMENTS

A possible layout for a furniture or fixture plant rough mill is shown in Figure 1. This layout provides for a crosscut first operation, i.e., rough boards are first crosscut to length and then ripped to desired widths. Another possibility is to first rip boards to the desired widths and then to crosscut to get the desired lengths. Depending on the dimension of the rough parts desired, rough part yield can very significantly depending on whether the board is ripped first or crosscut first. Hence some plants provide for the possibility of either crosscutting first or ripping first. In effect, such plants have two parallel processing lines. Boards are sorted and sent to the line where it is believed that the best yield can be obtained. A good deal of research has been conducted to determine the best cutup strategy. Currently, most furniture plants crosscut first. However, many are beginning to convert to rip first operations because research has shown that rip first lines will generally produce better yields.[3] Hence, there is a significant diversity in the sequence of processing steps used by the industry. A robust vision technology, one that can serve a significant percentage of the companies within the industry, must be adaptable so that it can accommodate whatever processing sequence that is preferred by management.

The goal of any automation activity must be to maximize the benefits obtained from the automation effort, That is, the investment in, automation equipment must be offset by a reduction in recurring costs and/or increase in yields obtained from the raw material. Attempts must also be made to minimize the cost of the automation equipment. Consideration of all three of these variables provides the means to obtain the optimum benefit.

Figure 2 shows a way to automate the rough mill in Figure 1. By using the output of only one vision system to determine the sawing strategies for both the crosscut and rip operations, one gets the maximum utility out of the investment in the vision technology. Considering the potential "high" cost of this technology, getting maximum utility out of it is very important. However, getting maximum utility out of the vision system makes little sense if the materials handling costs required to move the material from the vision to the crosscut and then to the rip saws is extremely expensive. Hence system design must take into consideration the overall materials handling problem.

An automated rough mill must be able to handle at least the same volume of material as the manual rough mill operation it is to replace. For the layout in Figure 2 this means that the automation system must be able to put an average of two to three linear feet per second through the crosscut saw.

An automated rough mill must provide management with at least the same flexibility they have in a manually operated rough mill. This means the vision system must be able to identify most of the common features that occur in lumber. These include knots, holes, wane, stain, mineral streak, decay, blue stain, splits, and checks. The species that the system must be able to handle include white oak, red oak, walnut, cherry, maple, mahogany, poplar, hickory, ash, and white pine. There is a significant variation in both color and grain pattern among these species. Furthermore, hardwood lumber comes in random widths. The average width. of a hardwood board today is approximately seven inches. While the vast majority of hardwood boards have widths less than 20 inches, there exists boards over 20 inches that are processed. Hardwood lumber comes in a variety of lengths with the maximum length being

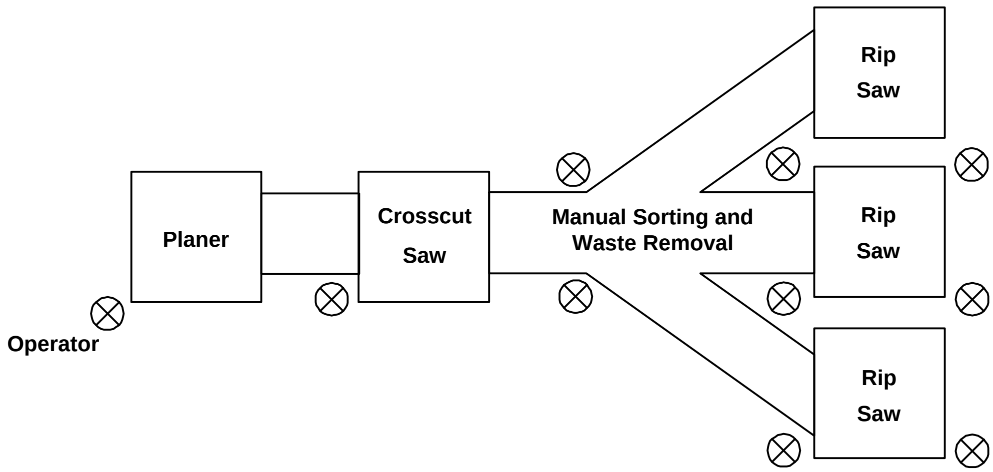

Figure 1. A manual crosscut first rough mill.

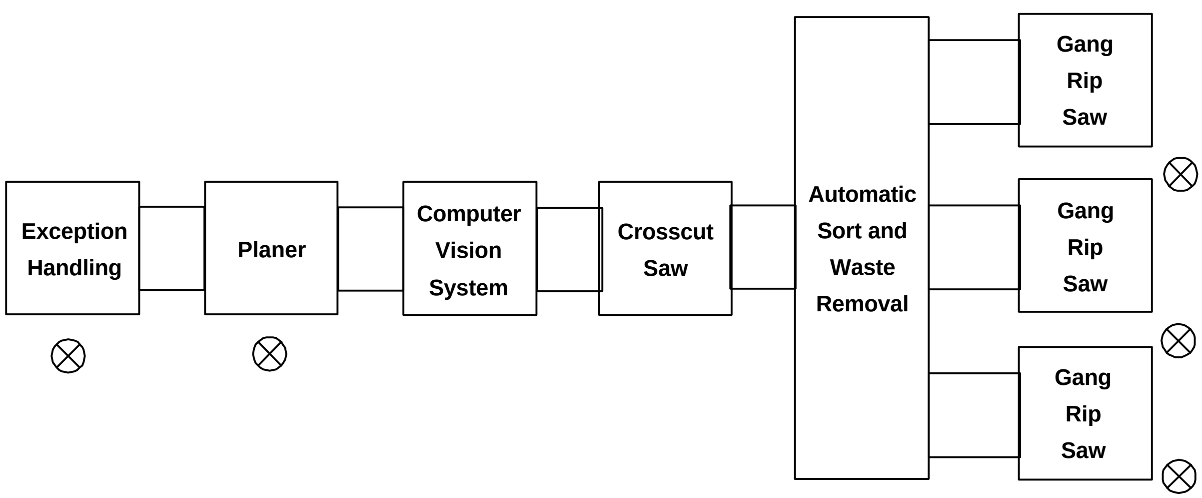

Figure 2. An automated version of the crosscut first rough mill.

around 16 feet. The thickness of material usually processed ranges from 3/4 of an inch to slightly over two inches. Therefore, the automatic system must be able to handle boards up to 16 feet long, up to 20 inches wide, and up to 2 1/4 inches thick.

To provide the same flexibility as a human sawyer, an automated rough mill must be such that it can be tailored by management to meet the processing objectives of the plant. This flexibility means that the vision system must be able to measure specific characteristics of each defect type. These characteristics are the means by which the tailoring is accomplished. For example to determine whether a knot is a removable defect typically depends on its diameter, whether it is sound or unsound, and/or whether it is tight or loose. These properties must be measured by the vision system so that decisions based on these qualities can be made. A study has been conducted to determine the characteristics that must be measured.[4] However more work is still needed to create a complete list. A goal of the study must be to determine this complete list of characteristics.

An automated rough mill must perform at least as well as a manual rough mill operation. The performance level of human sawyers has not been well quantified. One study suggest that human performance may not be very good at all.[5] But one cannot make any inference as to how well an automatic system must perform in order to favorably compete with the human rough mill employee. In general, the rough mill employee is typically an entry level position with a pay at the minimum wage. Rough mills are cold in winter, hot in summer, noisy and dusty the year round, and the work is tiring. Human performance probably deteriorates as the day progresses. Another goal of this research activity is to quantify the performance level of humans so that performance parameters can be established for automatic systems.

As with any automatic system that processes material as heterogeneous as wood, methods for handling exceptions must be provided. A goal of an automated system is to minimize the number and types of exceptions that must be handled. With boards there appears to be only one real exception that must be handled manually. This invollves warped boards. After drying, there is always some small amount of material that becomes badly warped. Developing materials handling methods for allowing for every possible variation caused, by warp would be very costly. Therefore, a method for handling the warped material must be provided. In the situation shown in Figure 2, the exception handling involves using a human operator to crosscut the warped material into several acceptable straight lengths, sending the resulting material though the automatic system. In this instance the vision system would be used to only determine the rip cut sawing strategy.

However, one other exception must handled for the automatic system shown in Figure 2. Boards over the maximum width handled by the vision system must be considered exceptions as well. Exception handling in this case might involve ripping these wide boards into narrower widths. Admittedly, doing so would markedly affect yield but if an appropriate maximum width is chosen only a very small percentage of material would have to be subjected to this type of exception handling. As technology advances this type of exception handling will no longer have to be considered.

3. DESIGN PHILOSOPHY

As should be readily apparent the requirements for the vision system are not precisely known at this time. In fact, part of the research effort is to arrive at a more precise problem statement as the research is being conducted. Hence the design of both the software and hardware subsystems must provide a great deal of flexibility. Obviously, incorporating flexibility into the various designs does not come free. The cost is that everything must be over designed with the realization that the final commercially viable system probably will not incorporate all the features of the test system.

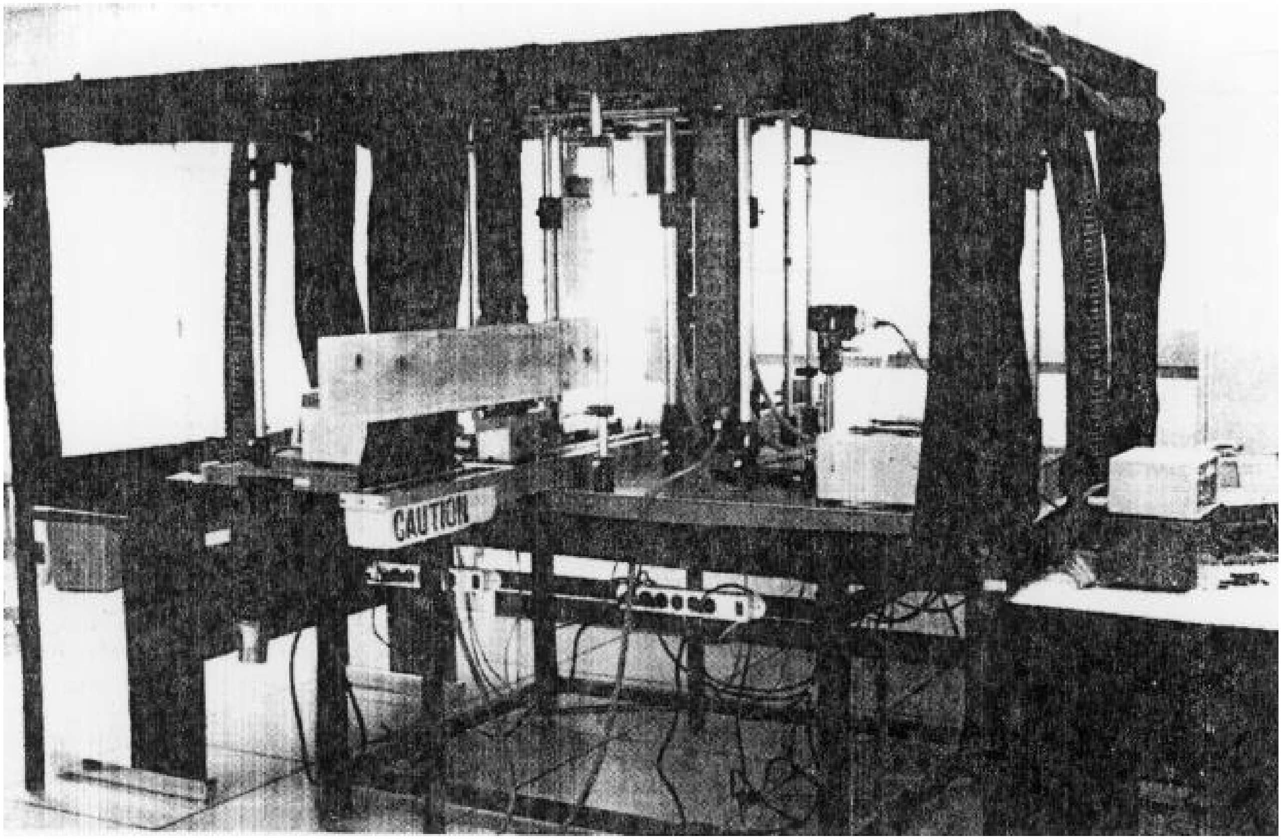

Figure 3. Prototype used in imaging system development.

For example, the imaging system used on the prototype will employ a number of sensors including color cameras, an x-ray imaging device, and imaging spectrometers. Obtaining data from all these sensors allows us to determine which sensors are important and which sensors are not. As the research progresses, it may be found that only that only a subset of these sensors are required. Humans perform defect detection and identification tasks using only color vision.

In the following, each of these design activities will be discussed. The methods used to provide optimum flexibility will be discussed.

4. IMAGING SYSTEM HARDWARE DEVLOPMENT

While optical science is based on a firm theory, the development of a complete imaging systems involving light sources, imaging devices, lenses and the like requires a good deal of experimentation. The goal of the experimentation is to find the best imaging and lighting geometries. Because of the need for this experimentation an optical breadboard with a freestanding cloth enclosure was combined to form a “prototype” system. This system is shown in Figure 3. Because of the diversity of the parts commercially available for use with optical breadboards the prototype allows the components described below to be easily mounted without the need for designing and for milling special purpose mounting apparatus. The prototype also allows the various components to be re-positioned with ease. This facilitates the type of experimentation that is associated with establishing the best imaging geometry. Though being somewhat expensive, this optical breadboard system has been extremely important in the imaging system hardware development activity.

In its final form, the components of the imaging system will consist of two color line scan cameras (one for imaging each side of a board), light sources for illuminating the imaged region, a x-ray imaging system, two imaging spectrometers (again, one for imaging each side of a board) and an object detection system. As of this writing the x-ray detection system and the imaging spectrometers have not been procured and, therefore, will not be discussed in any detail.

4.1 Color camera and lens system

To detect splits and checks of the widths required by industry means that the cross board spatial resolution for the color cameras must be at least 64 picture points (pixels) per inch. An examination of the autocorrelation function shows that cross board variations are much greater than along board variations. This suggests that along board spatial resolution can be less than the 64 pixels per inch cross board spatial resolution. Initial experiments suggest that the along board spatial resolution need be no higher than 32 points per inch. Hence, by using rectangular pixels the amount of data that must be collected can be reduced by at least a factor of two.

Because of the resolution requirements, a line scan camera was selected for use on the prototype. Since humans perform the defect detection and identification tasks with color vision and because color characteristics of wood is important in the manufacture of furniture, it was decided that a color line scan camera should be used.

The camera used is a Pulnix model TL-2600RGB. At the time the camera was purchaed (October, 1988) it was the only color line scan camera on the market. It has 864 full color pixels, just enough elements to scan a 13 1/2 inch wide board at a spatial resolution of 64 points per inch. The camera does not have as many color pixels as we would like but it does allow one to image material wide enough to demonstrate proof-of-concept. The camera can be run at 2.5 megahertz, just fast enough to scan two linear feet of lumber in one second at an along board spatial resolution of 32 points per inch. Note that by appropriately controlling the flow of the material through the camera's field of view any along board spatial resolution can be achieved. This is the important flexibility a line scan camera provides since along board spatial resolutions of less than 32 pixels per inch might be possible.

Since the time the Pulnix camera was purchased, EG&G Reticon has introduced a color line scan camera with over 2000 color pixels, more than enough for the required board widths. Further, Sierra Scientific has introduced a line scan camera designed specifically for the continuous web inspection problem. It addresses the primary hardware problem associated with the web inspection, i.e., the "light budget." Currently only one model is available, the black and white VISIONEER 4050 TDI. However, a color version of this camera is being considered for development.

The real problem in designing a high speed scanning system is providing enough light to get good images. This is the light budget problem. To help address this problem a 35 millimeter lens was chosen due to its relatively short focal length. Also, a very fast lens was purchased, one with a minimum f-stop of 1.4. Unfortunately, image quality is so poor at 1.4 and 1.8 f-stops that buying the fast lens did not help in the light budget. An f-stop of 2.8 is currently being used on the system.

4.2 Light source selection

To have the greatest flexibility in system design it would be convenient if one could incrementally keep adding light until enough could be provided to solve the problem. The incremental increase in light intensity seems like an easy concept to understand and implement. However, there is a very important problem constraint that makes the concept of incremental increases in light intensity very difficult to achieve in practice. The side issue is the fact that to use simple computer vision methods

the light provided must be uniform across the area to be scanned. One way to incrementally increase light intensity and still be able to achieve uniform lighting, uniform to with 20 percent, is to use fiber optic light sources. A fiber optic light source consists of a bundle of optic fibers. One end of the bundle points at a light bulb. This bulb provides the source of the light. The other end of the bundle is such that the ends of the fibers all lie in a straight line with all the ends pointing in the same direction. The light from the bulb passes through the fiber and comes out the other end. Since all the fibers are pointing in the same direction the line of fibers illuminates a linear region. With an appropriate diffusing filter between the bulb and the end of the bundle where the light enters, very uniform lines of light can be created.

The important factors concerning the light intensity provided are the wattage of the bulb providing the illumination and the length of the line of fiber ends. Given that the bulb wattage is fixed the way to increase the intensity of the output is to shorten the length of the line formed by the fiber ends, i.e., using fewer fibers each of which has a larger diameter. To increase the light intensity all along the original length one uses multiple bulbs and fiber bundles with a line of fiber ends for one bundle being stacked on top of a line of fiber ends from another bundle. Obviously each bundle is still illuminated by one bulb.

A company that makes such stackable fiber optic light sources is the Fostec Company. These sources use a 150 watt tungsten halogen bulb and for this application an 11 inch fiber optic light line was selected. A configuration employing six fiber optic sources is currently being investigated. Four sources are used to illuminate the board face, two on each side. The other two light sources are used to illuminate the background seen by the camera. Using these additional light sources provides a clear boundary between the board and background without being concerned about shadows.

Another reason for using fiber optic light sources concerns the environment in which an industrial vision system will have to operate. Furniture and fixture plants are dirty places with lots of dust. Hence, each camera and set of light sources will have to be placed in an enclosure. The use of fiber optic light sources allows this enclosure to be more or less permanently sealed. The bulbs can remain on the outside of the unit with the fiber optic cables carrying the light into the enclosure.

In selecting the illuminator to use, there were three choices, incandescent bulbs, low pressure discharge bulbs, and short arc lamps.[6] Because of the way light is generated in low pressure discharge bulbs their spectral distributions are marked by a number of narrow fixed spectral lines, a distribution that is unsuited for collecting quality color imagery. Except for tungsten halogen technology, an incandescent bulb will typically have a 20 percent drop off in the amount of illumination it provides across the bulb life. Hence the only real choice here is tungsten halogen (T-H) technology. T-H bulbs only have a two percent difference in illumination across the life time of a bulb. T-H bulbs also have good color temperatures and T-H bulbs are relatively inexpensive. These are the reasons T-H bulbs were selected for use on the prototype.

Unfortunately, T-H bulbs do not have a very flat spectral response across the range from 400 nanometers to 700 nanometers. Initial experiments clearly showed that when T-H bulbs were used in conjunction with the Pulnix camera, poor quality color images were produced. To correct for the lack of a flat spectral curve across the 400 to 700 nanometer range, filters were used. These filter provide a means for obtaining good imagery form the imaging system but the use of these filter come take a high cost on the light budget of the system. The amount of light reaching the camera went down by a factor of eight when the filters were inserted in front of the lens.

To help compensate for this loss, the T-H EKE bulbs that were originally used were replaced with T-H EJA bulbs. The EJA bulbs produce about twice the illumination as EKE bulbs, Given our lighting geometry, the switch allowed an increase by a factor of four the amount of light reaching the camera. The cost was that the EJA bulbs have half the expected life time of the EKE bulbs.

Currently we are exploring the possibility of using Xenon bulbs, a short arc lamp technology. These bulbs have a basically flat spectral response across the 400 to 700 nanometer range. Hence filters should not have to be used. Theoretically this should improve our light budget by a factor of eight. However, these bulbs have some undesirable characteristics as well. It requires a substantial voltage to be applied to initially form the plasma that emits the light energy. Since Xenon bulbs contain gas under high pressure, one has to handle the bulbs with care. Also, Xenon light sources can be very expensive. However they do have a very good expected life time of about 1000 hours, ten times the life expectancy of the T-H AJE bulb.

The attraction to Xenon technology comes from some recent developments by General Electric. It is believed GE has developed a Xenon illumination system for use in automotive headlights. If this is the case Xenon illumination sources will become common place and hence their costs should drop.

4.3 Object detection system

As was pointed out above when the imaging system is collecting data at industrial speeds, voluminous amounts of image data is being generated. To reduce the computational burden only image data that is absolutely necessary should be collected. To assure that this is the case, an object detection system is used. The system used is an Optoscan system by Scientific Technologies Incorporated. This system is composed of an array of infrared lasers on 1/4 inch centers along a 24 inch length and an array of detectors also on 1/4 inch centers along a 24 inch length. A board breaking the path between any one of the lasers and its associated detector can be instantly determined by the system. Constant monitoring of the Optoscan device can be used to determine when a board is entering the imaging system so that image data need only to be collected just prior to that board entering the field of view of the camera. Similarly monitoring the Optoscan device can be used to determine when the other end of the board is entering the system. In this way the image data need only to be collected while a board is passing through the system.

4.4 Initial materials handling system

To initially test out the various imaging system components a simple materials handling system was needed to move samples through the fields of view of the imaging devices. A 6 foot long linear stage is used for this purpose. This Velmex linear stage uses stepper motors and is under complete computer control. This stage cannot move material at the speeds that would be required for a commercial system but it provides a convenient method for testing the performance of the imaging components and for evaluating various imaging geometries.

4.5 Computer interface

A high speed interface is being designed. This high speed interface is not a direct memory access (DMA) interface though it accomplishes the same objectives. DMA interfaces use the computers memory bus. Hence when an input is being performed, memory channel bandwidth is being taken up by the 1/0 operation. For purposes of this system design this is undesirable. Thus a different approach is being used. The interface being designed is of the shared memory type. Using this shared memory interface image data can be input to one bank of memory while the processor is processing data in another bank of memory without any reduction is processing speed.

4.6 X-ray and imaging spectrometers

A consistent problem throughout the development activities has involved the detection of knots. In each hardwood species there is always some knots that have approximately the same color as clear

wood. Detecting such knots is a difficult task. To aid in the detection and identification of knots an x-ray scanner will be added to the prototype. The scanner to be used will be very similar to the ones used to check luggage at airports. It will be able to image material that is 17 1/2 inches wide at speeds of approximately two to three linear feet per second. While the spatial resolution of the x-ray scanner will not be as high as the color camera's, it will be satisfactory for knot detection. Since the boards to be imaged are a maximum of two inches thick, the amount of radiation required to image these boards is minimal. Similar x-ray scanning systems are already in use at a number of softwood lumber mills. Using the x-ray scanner has a number of other beneficial aspects as well. It will also detect honeycomb which is a defect introduced during drying. It is hard to detect honeycone if only the surface of a board is examined. The x-ray system should also prove useful in detecting and identifying decay.

Imaging spectrometers will be used in an effort to determine whether a multispectral approach can be taken in differentiating dirt from potential board defects, sap stains from potential board defects, and weathering from potential board defects.

Neither the x-ray scanner or the imaging spectrometers have been procured. The plans are to add these imagers to the system this calendar year.

5. ALOGRITHM/SOFTWARE SYSTEM DEVELOPMENT

Suppose that an along board spatial resolution of 32 pixels per inch is used, a resolution that is half of the cross board resolution. Then, if each of the three color components for a pixel is one byte, a 13 1/2 inch wide board that is 16 feet long would generate almost 16 megabytes of data from each of its two sides. That is a total of almost 32 megabytes for the whole board, a total that must be collected in four seconds. This means that to process this board at the required rate of two linear feet per second, four megabytes of color image data must be processed each second. If one adds in the data collected from the other sensors, the amount of data that will have to be process will be much higher than this figure.

This data rate demands that an attempt be made to reduce the computational complexity of the analysis. Given that the average hardwood board is approximately 7 inches wide, most boards are going to be significantly narrower than 13 1/2 inches. Hence one way to reduce problem complexity is to develop simple methods for differentiating pixels of background from pixels of board. Remember the imaging system must always be set up to image the widest board handled by the system. The prototype will handle boards up to 13 1/2 inches. Since one can control the color of the background used in the system very simple, supervised pixel-by-pixel methods can be used to differentiate pixels of back-ground from pixels of board.

A second possible saving comes from the consideration of the type of lumber used in furniture and fixture plants. These plants use only boards from the higher lumber grades, i.e., first and seconds, one common, and two common lumber. Studies have shown that an average board from the poorest of these grades, i.e., two common lumber, has no more than 15 per cent of its surface area being something other than clear wood. On average boards in the higher grades have lower percentages than this. Hence, if a simple method could be found for differentiating clear wood from other board features then sub-stantial savings could result.

References 1 and 2 describe a simple method for performing this image segmentation operation. These segmentation methods are adaptive so that they can handle the complete range of hardwood species. They have been extensively tested and appear to work in a completely species independent manner. Unfortunately, in some hardwood species knots have approximately the same color as clear wood. In these instances the adaptive segmentation sometimes fail. As was stated above, to help with this problem an x-ray system will be incorporated into the prototype.

The use of adaptive segmentation methods requires that the actual segmentation operation cannot be started until image data from the entire board has been collected.

Once the segmentation operation is complete, the recognition of the features appearing in each of the segmented regions must be accomplished. To provide flexibility in recognition system development the recognition software must be such that incremental additions to system knowledge can easily be made. The addition of new knowledge should in no way affect the knowledge already possessed by the system. This means, from a software engineering point of view, that the recognition system must be composed of a number- of loosely coupled modules whose order of execution depends on problem dependent parameters. A very good way to achieve this program structure is to use expert system techniques.

References 1 and 2 describe some of the progress that has been made on developing this component of the software system. The work on the recognition system was just begun during calendar year 1989. Hence it has not been as extensively tested. The recognition system under development uses a combination bottom-up, top-down analysis strategy.

6. IMAGE PROCESSING HARDWARE DEVELOPMENT

The adaptive segmentation methods that have been developed are based on looking at two-dimensional histograms of the red and blue color channels. The segmentation techniques involve looking for structure in this 256x256 red-blue histogram. Once the structure has been found, a pixel-by-pixel labeling is performed. The 2.5 megahertz scanning rate is such that the red-blue histogram can be formed as the data is taken from the camera. Finding structure in the two dimensional histogram involves only examining a 256x256 pseudo-image and does not require any further processing of the 32 megabytes of color image data. Some noise filtering is required on the output of the pixel-by-pixel labelling. The pixel-by-pixel labelling and the noise filtering both lend themselves to a pipeline type of hardware implementation.

The segmentation operation conceptually segments the board into a number of disjoint areas each of which corresponds to a feature of the board, i.e., knot, hole, etc. The recognition process involves taking one of these segmented regions and attempting to recognize the board feature present at this region location. Given that there is little correlation between a board feature and one location and one some distance away, an obvious way to speed up the recognition process is to use multiple experts, where each expert is equally competent.

Translated into computer engineering jargon, the way to implement the recognition system that can run in real-time is to use a tightly coupled, multiple instruction stream, multiple data stream (MIMD) architecture. For individuals unacquainted with this jargon, the recognition system should be implemented using multiple processors with all of the processors sharing the same memory. Further each of the processors should be running the same program, the same recognition expert system.

The advantage of using this approach in the implementation is that it seemingly provides the most future flexibility. One need only review the computer company literature to see that a number of manufacturers are using MIMD architectures to improve price/performance of their product.

Given the above, the hardware implementation strategy that is currently being pursued is one where a pipeline type of architecture is used to do the segmentation. The output of the pipeline is fed into a MIMD architecture machine using a shared memory interface. The shared memory concept allows the MIMD machine to process data taken from one board while data from another board is being put into its memory by the pipeline processor. The shared memory idea does not impose any restrictions on the

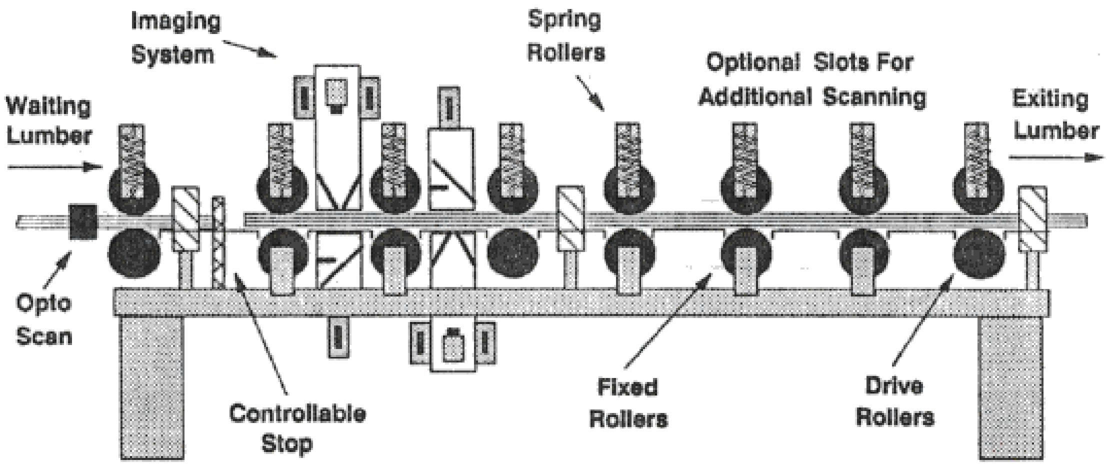

Figure 4. Material handling system for the full scale prototype

memory bus of the MIMD machine, so its processing speed is unaffected by the input operation that is occurring.

In Section 2 it was pointed out that some furniture and fixture plants use crosscut first processing strategy, others use a rip first processing strategy, while still others provide methods for either crosscutting or ripping first by having two separate processing lines. Actually, the situation is even more involved than this. The material flow, processing sequence, and place where the computer vision system should be located can vary significantly depending on the product or products being produced. Hence in designing the materials handling system that is to be used on the prototype, some assumptions are required in order to design this system. It is assumed that we are dealing with either a crosscut first, a rip first, or a crosscut or rip first type of operation. For purposes of this discussion consider the set of circumstances illustrated in Figure 2. In this case the purpose of the materials handling system is to move variable length boards up to 16 feet long through the imaging system at speeds up to two linear feet per second. The goal is to have this system be able to with stand the rigors of continuous use in a rough mill environment.

The system must provide a place for a board to enter the system. It must also provide a place from which the board can be removed. However, unlike the final commercial system that will accept boards directly from a skip planer and feed the boards into a saw, this materials handling system must provide a mechanism for workers to place a board for entry into the system and a place for workers to remove boards once they have passed through the imaging system. This means that the length of the system must be over twice as long as the longest board to be handled. The additional length is required to allow room for the board to be accelerated to the desired speed prior to entering the imaging system, room for the Optoscan and the two imaging subsystems (one for each side of the board), and finally room for the board to be decelerated back down to zero velocity.

The primary design consideration, is to design a minimum cost system, to design a system that is very reliable, and to design a system that can use inexpensive materials handling methods to bring boards to it and to transport boards to the saws. The current concept being pursued is shown in Figure 4. This system provides for five scanning locations, two for the color cameras, two for the imaging spectrometers, and one for the x-ray scanner.

This system should go out for bid in February-March time frame. A company familiar with the materials handling problems of the furniture and fixture industry will be contacted to complete the design and build the system. It is hoped that the materials handling system can be completed by this August.

8. CONCLUSIONS

Over the last few years significant progress has been made on developing a computer vision system for the inspection of hardwood lumber. On the software side, work is continuing on the development of recognition methods that are robust enough to handle the variety of species and variety of feature types that must be considered.

On the hardware side work is continuing on creating all the needed hardware to solve this inspection problem. As of this writing much of the vision system imaging hardware has already been assembled and tested. A design for the materials handling "system" is being created. The complete prototype should be finished by March, 1991.

9. REFERENCES

1. Conners, R. W., C. T. Ng, T. H. Cho, and C. W. McMillin, 1989, "Computer Vision System for Locating and Identifying Defects in Hardwood Lumber," **Proceedings of SPIE,** Applications of Artificial Intelligence, VII, March 28-30, Orlando, Florida, pp. 48-64.

2. Conners, R. W., T. H. Cho, and P. A. Araman, 1989, "Automated Grading of Rough Hardwood Lumber," to be published in the **Proceedings of the Third International Conference on Scanning Technology in Sawmilling,** San Francisco, California, October 5-6.

3. Gatchell, C., "Rethinking the Design of the Furniture Rough," **Forest Products Journal,** Vol. 33, No. 6, 1987, pp. 8-14.

4. Huber, H., S. Ruddell, and C. McMillin, "Industry Recognition of Wood Defects," under pereparation.

5. Huber, H., C. McMillin, and J. McKimmey, "Lumber Defect Detection Abilities of Furniture Rough Mill Employees," **Forest Products Journal,** Vol. 35, No. 11/12, 1987, pp. 79-82.

6. Oriel Corporation, **Light Sources, Monochromators, Detection Systems,** 1988.