A Multisensory Machine Vision System for Hardwood Defect Detection

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Abstract

Over the next decade there is going to be a substantial change in the way forest products manufacturing industries do business. The economic forces responsible for these changes include the heightened economic competition that will result from the new world economy and the continued increase in the cost of both raw material and labor. These factors are going to force companies to seek methods for reducing costs, for increasing productivity, and for improving quality control. The primary vehicle that will help companies accomplish these cost cutting and quality control objectives is going to be the microcomputer. Over the next decade microcomputers should be developed that can execute several hundreds of thousands of instructions per second. Perhaps the greatest impact this technology will have is that it will make machine vision systems for locating and identifying defects in lumber economically feasible. Unfortunately, wood is a very, very heterogeneous material. Hence developing machine vision systems for locating and identifying defects is not going to be an easy task. This paper describes research aimed at creating a general purpose machine vision technology for the forest products manufacturing industry.

Introduction

Over the next decade there is going to be a substantial change in the way forest products manufacturing industries do business. The economic forces responsible for these changes include the heightened economic competition that will result from the new world economy and the continued increase in the cost of both raw material and labor. These factors are going to force companies to seek methods for reducing costs, for increasing productivity, and for improving quality control.

The vehicle for this change is going to be the highly reliable, relatively inexpensive microcomputer. To understand the impact these devices can and will make on forest products manufacturing industries one need only consider the expected evolution in these devices over the coming years. Today's benchmark processor is the Intel 486 microprocessor that runs at clock speeds of 33 megahertz and that can execute 27 million instructions per second (MIPS). Intel estimates that by the year 2000 a benchmark processor will be running at clock speeds of 250 megahertz and will be able to execute 2 billion instructions per second (2,000 MIPS).

Inexpensive computers possessing this type of computational capability will have a plethora of potential applications in forest products manufacturing operations. Certainly the availability of such machines will precipitate the development of very sophisticated computer aided design (CAD) systems and computer aided manufacturing (CAM) systems. Most certainly, they will precipitate the development of many of the potpourri of technologies associated with advanced computer integrated manufacturing (CIM) systems.

Finally, the ready availability of inexpensive "high speed computers should also spur the development of machine vision systems for process and quality control. The major limiting factor in creating such systems is the cost of digital hardware needed for real-time implementation. As the computational capabilities of microprocessors increase up to and beyond 2 billion instructions per second, more and more sophisticated yet relatively inexpensive machine vision systems should become available for both process and quality control.

Unfortunately, wood is a very, very heterogeneous material. Its appearance varies significantly from species to species and from one board to another within a species. The way a feature such as a knot manifests itself varies from one board to another within a species and even varies more significantly across species. Wood is perhaps the most heterogeneous of all the raw materials used in any manufacturing process. Because wood is so much more heterogeneous than other raw materials, it is doubtful that a vision technology developed for any other industry will be able to inspect lumber. Because wood is such a heterogeneous material, the research and development time required to develop a machine vision system that can accurately locate and identify defects is going to take time. Consequently, if a machine vision technology for inspecting lumber is to be developed, research efforts aimed directly at this development must be conducted.

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. Current evidence suggests that a significant improvement in defect detection and recognition accuracies can be obtained if a variety of different sensors are used. In particular, current evidence suggests that an appropriate array of sensors to use on this problem includes two color cameras, one for imaging each board face, an x-ray imaging system, to aid in knot detection and recognition, and two laser based ranging camera systems for gauging board thickness and for detecting and recognizing defects that affect perceived board thickness, e.g., holes, split/check, wane, etc.

Background

Any machine vision system is composed of an imaging subsystem that creates digital images of the item or items to be inspected; a materials handling subsystem for moving the items to be inspected through the imaging components; a computer vision software subsystem that is composed of algorithms that instruct a computer how to go about analyzing the digital images created by the imaging subsystem; and, finally, a computer that executes the computer vision software system and controls all the other subsystems.

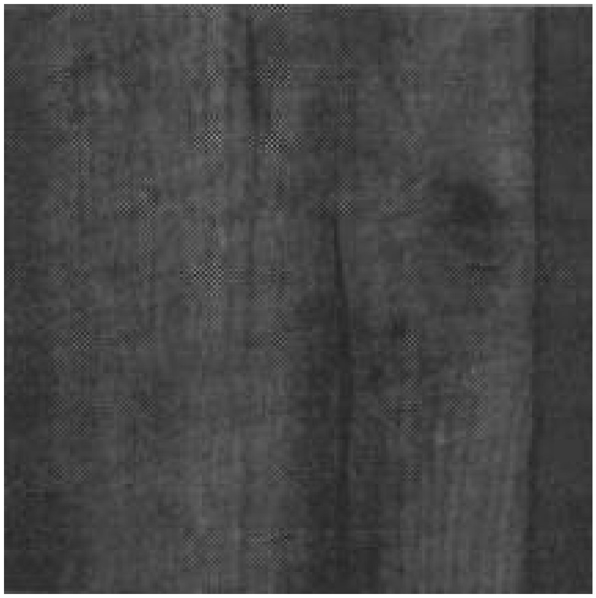
One of the very first decisions that has to be made in designing a machine vision system is the selection of the sensor or sensors to use in the system. Very early work on automatic defect detection focused on using black and white image data obtained from a normal solid state camera [Conners et al, 1989, Koivo et al, 1989 Paul et al, 1988] However, the focus at Virginia Tech quickly shifted to the use of color image data [Comers et al, 1987] again, obtained from standard solid state cameras. The motivation for the use of color imagery comes from the fact that workers can locate and identify wood defects based solely on input from the human color vison system. Given this sensor selection the thrust of the work then centered on developing the needed computer vision algorithms that would be able to accurately locate and identify wood defects. A good deal of effort has gone into this activity. First, a robust segmentation system has been created [Conners, 1987; Conners et al, 1989]. This system can locate areas that potentially contain a defect based solely on color information. Approximately two years of effort have gone into developing this segmentation system. It has been tested on surfaced samples of red oak, white oak, cherry, maple, yellow poplar, hickory, walnut, and even white pine. It has also been tested on rough samples of red oak, cherry, maple, and yellow poplar. The segmentation methods work in a species independent manner. They are completely adaptive, automatically adapting to the requirements of any species without the need for parameter changes. Experiments indicate that this system works best on surfaced material and works well, but with reduced sensitivity, on rough samples. The reduced sensitivity results from shadows created by the rough surface during imaging and also because of surface discolorations typically appearing on rough lumber surfaces, e.g., dried sap, sticker marks, and dirt.

Once satisfactory progress had been made on the segmentation system, the system that locates areas of potential defect, attention was turned to creating the recognition system, the system that identifies the type of defect present at each of the locations found by the segmentation system. Historically, the most difficult task in any computer vision system is the development of recognition algorithms. It is typically quite difficult to create methods that are consistently accurate. Given the perceived complexity of the task, it was decided to concentrate on developing methods for recognizing only the four most common defect types, i.e., knots, wane, holes, and split/check. Approximately two years of effort have gone into developing a recognition system that can identify these four defect types. This system works in a completely species independent manner and has been tested on both rough and surfaced lumber samples. The recognition system has been structured as an expert system that uses a Blackboard framework [Cho, 1991; Cho et al, 1990]. It employs uncertain reasoning methods. It employs what is believed to be the most sophisticated type of control paradigm, a heterarchical analysis strategy, the same strategy believed used by the human vision system.

Figures 1 and 2 show representative processing results obtained from the computer vision subsystem that has been developed for the analysis of color image data.

Motivation for a Multisensor Approach

A good deal has been learned during this development activity. It has been found that in every hardwood species there are always knots that have almost exactly the same color as clear wood. Using only color information these knots are very difficult to locate and when located are very difficult to identify. As long as bark or the cambium is present wane detection can easily be accomplished using either black and white or color data. However, if debarkers are used the cambium maybe ripped away along with some sapwood. In these instances, wane detection can be a problem. Even when knots are completely or partially detected by the segmentation system they can be difficult for the recognition system to identify. The problem is their innate variability. This variability makes the problem of arriving at reliable recognition rules very difficult.



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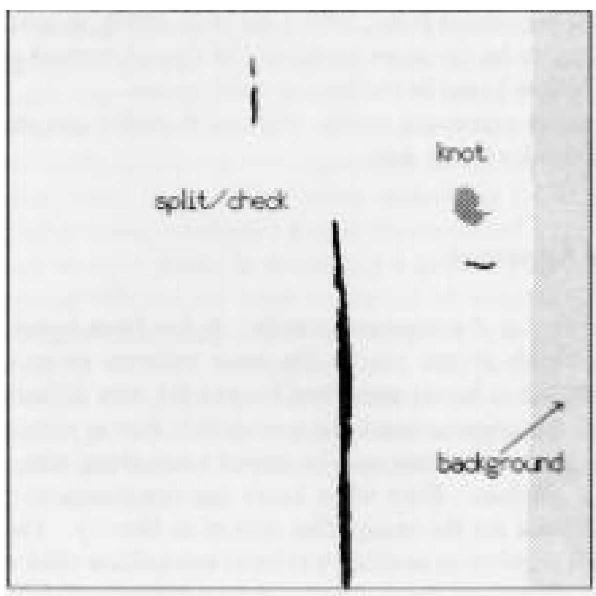
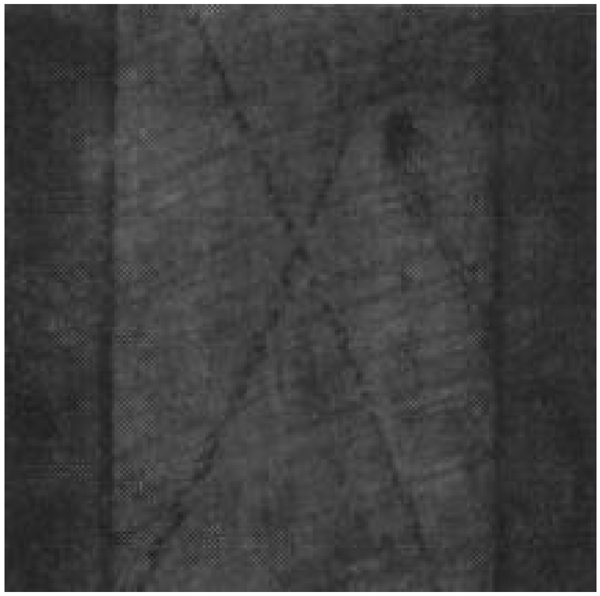


(b)

Figure 1: Part (a) A black and white version of a color image of a rough red oak sample. Part (b) The results obtained from the computer vision system that has been developed at Virginia Tech. Note the system has difficulty determining the full extent of knots.



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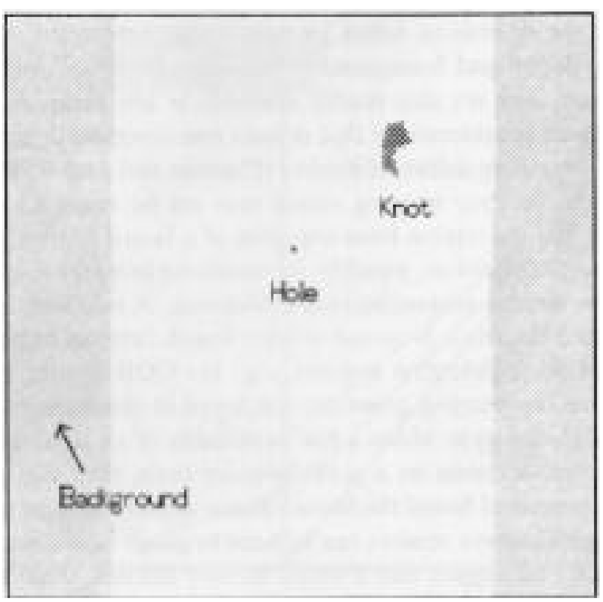

(b)

Figure 2: Part (a) A black and white version of a color image of a rough maple sample. Part (b) The results obtained from the computer vision system that has been developed at Virginia Tech. Note the system has

difficulty determining the full extent of knots. The system is able to ignore the marks on the board except at the intersection of the marks which is mistakenly labeled as being a hole.

A number to attempts have been made to find software solutions to the above problems, in particular, the knot detection and recognition problems. But none of these attempts has succeeded. The problem stems from the fact that the presence of a defect must be inferred based on some nonunique color properties. A knot can be reddish brown but it can also be the same color as clear wood. Hence, when only color information is used there are a variety of different ways in which a defect can manifest itself so that it eludes detection altogether or, if detected, there are a variety of different ways a defect can manifest itself that make it very difficult for a recognition system to determine its true identity. While these problems occur on both surfaced and rough lumber, they are particularly exacerbated on rough lumber where sticker marks, dirt, the rough surface, water marks and dried sap all reduce the sensitivity of both the segmentation and recognition system [Cho. 1991].

A problem examination suggests that what is needed are additional imaging sensors, imaging sensors that can help disambiguate both the detection and recognition problem. Since knots are such an important defect type, any additional imaging sensor must be such that it will aid in the knot detection and recognition problem. The goal is to have any additional imaging sensors optimally augment the use of color imagery. Interestingly the idea of augmenting optical scanning systems with additional sensors goes back almost ten years [Szymani and McDonald, 1981]. Candidate sensors include microwave sensors [Szymani and McDonald, 1981; Portala and Ciccotelli, 1990; King, 1978], capacitance type sensors [McDonald and Bendtsen, 1986; Steele et al, 1991], and x-ray imaging devices [Szymani and McDonald, 1981; Portala and Ciccotelli, 1990; Sicardy, 1985]. Of these devices the best choice for an additional imaging system appears to be an x-ray imaging device. X-ray imaging devices are known to be able to detect knots, a detection capability that is based on density differences between knot areas and areas of clear wood. This detection capability has been verified by the many experiments that have been done using computer tomography (CT) images of logs. All the analysis that has been done clearly indicates that knots are easily detected in CT images [Benson-Cooper et al, 1982, Funt and Bryant, 1987, Taylor et al, 1983]. This capability has also been verified at Virginia Tech using some available CT image data of a red oak log section. This CT image data can be used to simulate what an x-ray image of a board will look like. Figure 3 shows such a simulated x-ray image of a one inch board. Note how clearly the knots stand out in this simulated image. In addition to being able to detect knots it is also known that x-ray images can be used to detect holes, split/check, wane, decay, and honeycomb. Not only are x-ray imaging systems versatile in the number of defects they can detect they are also readily available in low radiation, yet high spatial resolution units. Perhaps it is because of these considerations that at least one company is using an x-ray imaging scanner as part of an automatic system for grading softwood lumber [Flatman and Bodell,1989 Kenway, 1990].

However, even the addition of an x-ray imaging sensor may not be enough to facilitate the detection and recognition of defects. Variations in absorption from one area of a board to another area of the board can be caused by inhomogeneities within the board or, possibly, by variations in board thickness. To disambiguate the exact cause requires a method for directly measuring board thickness. A relatively inexpensive yet very accurate method for directly gauging board thickness is to use a laser based ranging camera system, a system that is similar in concept to laser based wane detection systems, e.g., the COE system, but with significantly higher spatial resolution. Figure 4 shows the imaging geometry employed in this laser based ranging camera system. Such systems can measure board thickness to within a few hundredths of an inch. Since these systems provide a direct method for measuring board thickness on a point-by-point basis, they also provide a direct method for detecting any defect that affects perceived board thickness. These defects include split/check, holes, wane, saw marks, etc. Data from laser ranging camera sensors can be used to gauge board roughness.

Experiments performed to date all suggest that it would be very difficult, if not impossible, to arrive at a set of computer algorithms that can accurately locate and identify defects based solely on the use of color data. Hence, if the problem is to be solved additional hardware is needed. The goal of the additional hardware, i.e., the additional imaging systems, is to reduce, hopefully markedly so, the problem of designing algorithms that can accurately locate and identify defects.

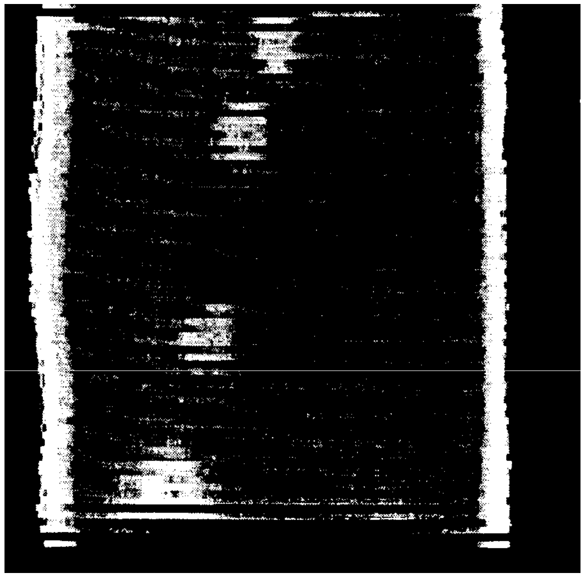

Figure 3: A simulated version of an x-ray image of a one inch thick board. This simulated image was created using available computer tomography (CT) imagery of a red oak log section. Note how prominent the knots are in this simulated image. This means knots should be relatively easy to automatically detect in x-ray images.

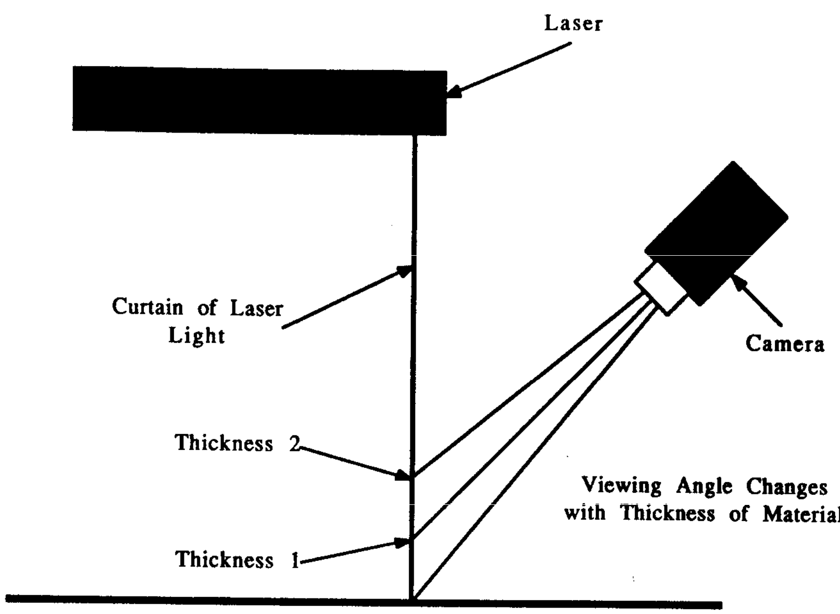

Figure 4: The imaging geometry that will be used in the laser based ranging camera system that is being designed and tested at Virginia Tech. Note that the thickness of a board at a particular point can be measured by determining the position of that point within the imaged field of view.

A Full Scale Prototype Machine Vision System

Even as the above described experiments involving the use of color imagery were being conducted, it became clear that the development of a full scale machine vision prototype system was going to be necessary if any marked progress was going to be made on this problem. To minimize cost all inital experimentation had been performed using standard off-the-shelf image processing hardware. Hence the spatial resolution of the camera used in the initial studies was 512 x 480. At 64 points per inch spatial resolution this allowed the experiments to consider only images of an approximately 8 inch by 8 inch area of a board surface, Unfortunately, it is very difficult to extrapolate the results obtained over such a limited area to obtain estimates of what results might be obtained on full sized material used by industry. Hence, designing a full scale prototype has become a thrust of the current research program.

Initial full scale prototype development has concentrated on the design and construction of two important components, the color imaging subsystem and the materials handling system for moving boards through the various imaging sensors that comprise the complete imaging subsystem. As of this writing most of the components for the color imaging subsystem have been purchased and integrated on a system called the "prototype." The components of the color imaging subsystem include two Pulnix color line scan cameras each with 864 color pixels resolution; two 50 millimeter 2.8 f-stop Pentax lenses; a number of fiber optic light lines for illuminating the board surfaces; and special filters for normalizing the combined effect of the spectral characteristics of silicon and the spectral characteristics of the tungsten halogen bulbs so that high quality color images can be obtained using only one offset and gain setting for each camera's analog-to-digital converter [Conners et al, 1990].

A high speed computer interface that connects the two line scan cameras to an IBM PS/2 Model 80 computer has been designed and built. It allows the cameras to be run at their maximum clock speed of 2.5 megahertz, just fast enough to allow a 32 points per inch down board spatial resolution when boards move through the field of view at two linear feet per second [Drayer, 1991]. Finally, the color imaging subsystem incorporates an object detection system so that each camera does not have to start collecting data until a board is about to enter its field of view.

All these components have been integrated on what is called a "prototype" system that is made up of a 4 x 6 feet rectangular optical bench. The optical bench is enclosed in a free standing enclosure that prevents room light from affecting the images collected by the two color cameras. Figure 5 shows the "prototype" with all the above described components mounted on it. Currently, this prototype system can create color images of sample boards up to four feet long. A simple 6 feet long computer controlled linear stage is used to move samples through the color camera systems. Within two to four months this system should be able to create color images of both board surfaces simultaneously. This prototype system allows one to easily experiment with various imaging and lighting geometries. It also provides a convenient mechanism for integrating all the components together to see how well they all function in unison. With this optical bench setup only a very few, only about six components had to be especially milled in order to get all the components mounted. See Reference [Ng, 1991] for a detailed description of the various hardware components of the color imaging subsystem.

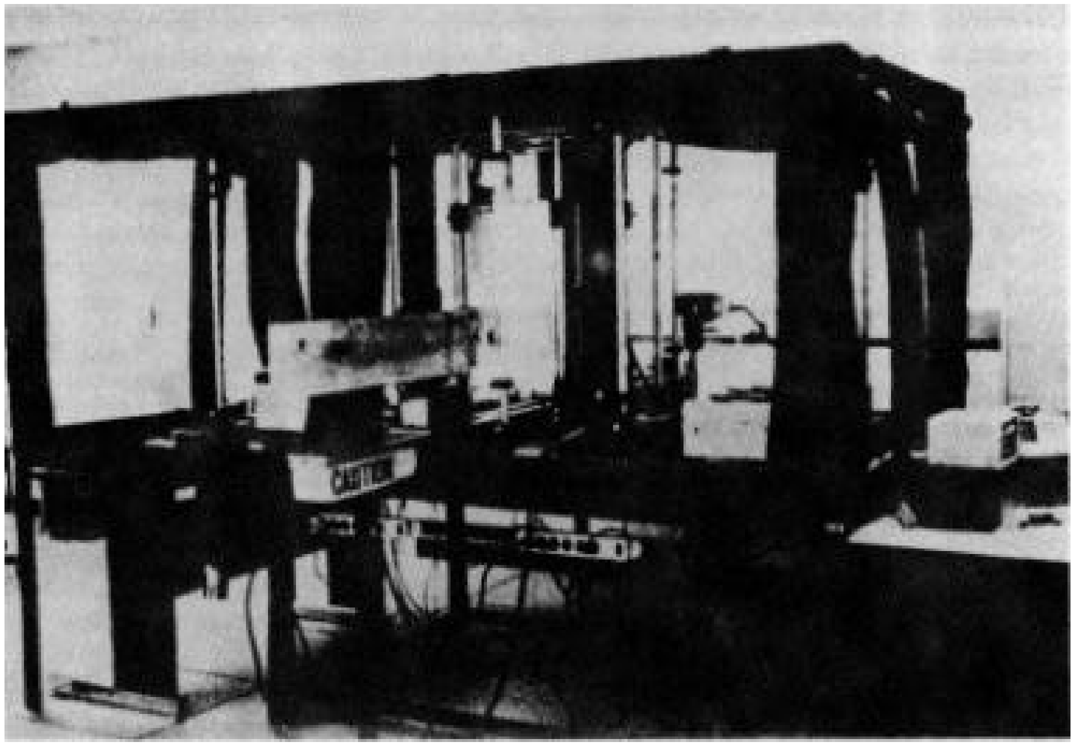

Figure 5: The "prototyper" system that has been used to assemble the various components of the color imaging subsystem.

Materials Handling Subsystem

With regard to the materials handling subsystem it was decided to let a company with experience in materials handling within the hardwood forest manufacturing industry design and build this subsystem. The requirements for the system were formulated at Virginia Tech, and Automated Lumber Handling Company (ALH) of Lenoir, North Carolina, was eventually selected to design and build the system. Figure 6 shows a preliminary drawing of the materials handling subsystem designed by ALH. This figure shows how the color cameras will be mounted on the material handling subsystem. It also shows the space on the materials handling subsystem that has been provided for mounting other scanning devices, e.g., the x-ray imaging system and the laser based ranging imaging system. In total, space for five scanning systems will be available, if needed. An object detection sensor is used to detect the presence of incoming lumber. A controllable stop is released when the waiting lumber is detected and the imaging subsystem is ready. After the stop is released, an encoding device is used to record the length of each board. Similar encoding devices will be used in downstream processing operations to accurately reposition scanned lumber for processing e.e., crosscutting to ripping.

The overall length of the system will be such that a board can be accelerated to a constant velocity (up to 4 linear feet per second) before the leading edge of a board enters the field of view of the first imaging device, then, to stop the board after the trailing edge has left the field of view of the last imaging device. A precision mechanism to drive the lumber through the imaging system will be needed. Adequate lumber support will be provided throughout to minimize up and down vibrations of boards, especially in the vicinity of the imaging sensors. Current plans are to use pneumatic pinch rollers to provide this support rather than the spring-loaded rollers shown in Figure 6.

Once the materials handling subsystem arrives at Virginia Tech in late February of 1991, dust free enclosures for the color imaging components will be designed and built. These components inside their dust free enclosures will then be mounted to the materials handling subsystem for testing.

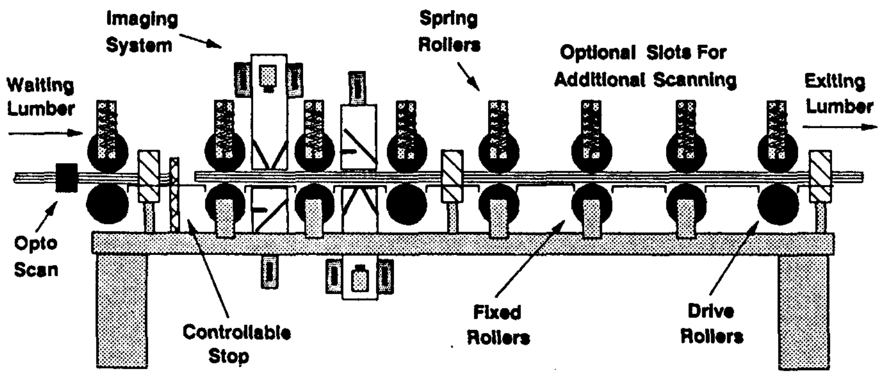

Figure 6: A conceptualization of the materials handling subsystem. The materials handling subsystem will move lumber through the imaging subsystem at a maximum of four linear feet per second. Two color camera systems are shown in this conceptualization. Space is provided for five scanning locations. Additional scanning systems to be mounted to the materials handling system include an x-ray scanner and a proprietary scanner.

Current Research Thrust

The ultimate objective of this research is to create a general purpose machine vision technology for the forest products manufacturing industry. All evidence suggest that it may difficult if not impossible to base such a general purpose technology on only color image information. Evidence suggest that data from other sensing systems is also going to be required. The thrust of the current research is directed towards investigating the utility of two imaging systems that seemingly will provide valuable additional information that will aid in both the detection and recognition of a number of different defects.

An immediate research thrust is to develop a laser based ranging camera system. Whale there are commercial laser based ranging camera systems on the market, these systems do not lend themselves to the high resolution examination of lumber or wood strips. Hence, an activity is underway to design and build two ranging camera systems that will work well on the lumber or wood strip inspection problem. A small working laser based ranging camera prototype is currently being configured. This prototype will establish the proof of concept. Once the concept is established two full scale laser based ranging camera systems will be designed and built. Each of these systems will be able to image boards up to 13-1/2 inches wide at a spatial resolution of 32 points per inch. Each of the identical systems will be fast enough to provide 16 points per inch down board resolution at board feed speeds of two linear feet per second. It will take approximately one year to design, build and test both of these ranging camera systems and another year to fully integrate them on the full scale prototype machine vision system.

As to the x-ray scanner system, tests are still being conducted to fully document its potential utility. The tests that are being conducted are using CT imagery available at Virginia Tech. Simulated boards such as the one shown in Figure 5 are being used in these tests. If the tests clearly indicate the utility of the x-ray scanning system, as it is believed they will, an x-ray scanning system will be purchased. A candidate commercial unit is one that is made by E, G, and G Astro Physics. The unit of interest, will allow 20 points per inch cross board spatial resolution and 10 points per inch down board resolution. Once the unit has been purchased a special high speed interface that will link this system to a microchannel I/O bus will have to be designed. Once the interface has been designed, built and tested, the x-ray scanner will be integrated into the full scale prototype machine vision system.

Summary and Conclusions

A good deal of progress has been made on developing a general purpose machine vision technology for the forest products manufacturing industry. However, much remains to be done. The development of the full scale prototype system is the key to future progress. It will for the first time allow full sized material to be imaged. It will provide a testbed that will both aid in the research and development activities needed to create the needed technology as well as providing a mechanism to establish the true merits of this technology to the forest products manufacturing industry once the technology is developed. The addition of the x-ray scanner and the two laser based ranging cameras also appears critical to future progress. All studies suggest that an x-ray scanner will markedly aid in both the detection and recognition of knots as well as a variety of other defects including decay and honeycomb. The laser based ranging cameras will aid in the detection and recognition of a number of defects including wane, split/check, and holes as well as disambiguating alternative interpretations possible in x-ray images. The integration of these additional imaging systems on the full scale prototype should markedly speed the development process allowing the creation of a truly robust machine vision technology within the next few years.

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