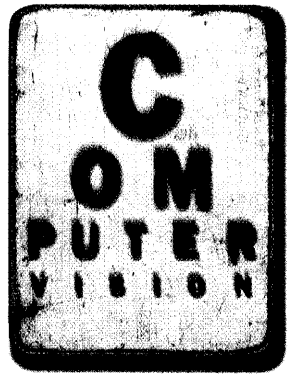
Machine Vision Technology for the Forest Products Industry



From forest to finished product, wood is moved from one processing stage to the next, subject to the decisions of individuals along the way. While this process has worked for hundreds of years, the technology exists today to provide more complete information to the decision makers. Virginia Tech has developed this technology, creating a machine vision prototype for wood products manufacturing.

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When a tree is felled, a process begins to maximize the value of that wood. The log is taken to a sawmill, where someone decides whether the wood is more valuable as lumber, veneer, or chips. If the log is made into lumber, boards cut from it must be edged and trimmed, a process that requires someone to decide how to trim off defective parts and make the board as valuable as possible. Then someone must examine the board and give it a grade—based on the quality of the wood and presence of defects—and this determines the board's selling price. Finally, at the rough mill, someone cuts the lumber again to produce defect-free dimension parts.

Much of this process is based on subjective decisions and incomplete information. When a sawyer trims a board, he knows only what he sees on the board's surface. As the board passes through the mill, decisions must be made quickly, and sometimes a board is trimmed or cut in a less than desirable way. Finally, when the board is graded, the grader makes decisions on the value of the board based only on what he can infer from an inspection. Since this is a subjective process, two people may assign different grades to the same board.

In the forest products industry, workers' decisions directly affect the quality and yield of the wood products created. Unfortunately, the process is slow and subject to error. Lumber is often improperly cut and trimmed, and boards are frequently incorrectly graded.[1] Furthermore, this manual process doesn't lend itself to the development of automated sawmill operations. Clearly, machine vision technology, with its ability to provide more complete information, could find a place in the forest products industry.

VISION TECHNOLOGY IN FORESTRY

To some extent, vision technology has existed in the industry since the early 1980s.[2] Various technologies, such as laser ranging and black-and-white cameras, have been used to measure the dimensions of logs and lumber. While this has been most useful in improving efficiency, it has done little to maximize the value of the resulting products. Much research, then, has gone into developing other technologies that can detect and plot features in the wood.

A useful technology must accurately identify the three features of a board that will affect its value:

- *Surface features:* knots, holes, splits, decay, discoloration, slope of grain.
- *Geometry features:* three-dimensional shape, warp, wane, variations in thickness.
- *Internal features:* voids, knots, decay.

Most research has gone into optical sensing methods, including cameras and spectrometers, which measure the intensity and color of reflected light.[3,4] These devices detect surface features and can be readily automated, but they will miss knots that are the same color as clear wood, or classify soil or grease on the board as a defect. They can also be confused by variations between species and by the roughness and moistness of the wood. Of course, they are of no use for detecting internal features.

Technologies that measure density of the wood can detect internal features, so much research has gone into developing machine vision systems using ultrasound, microwave, nuclear magnetic resonance, and X-ray technologies.[2] While these systems overcome some of the problems of optical systems, they

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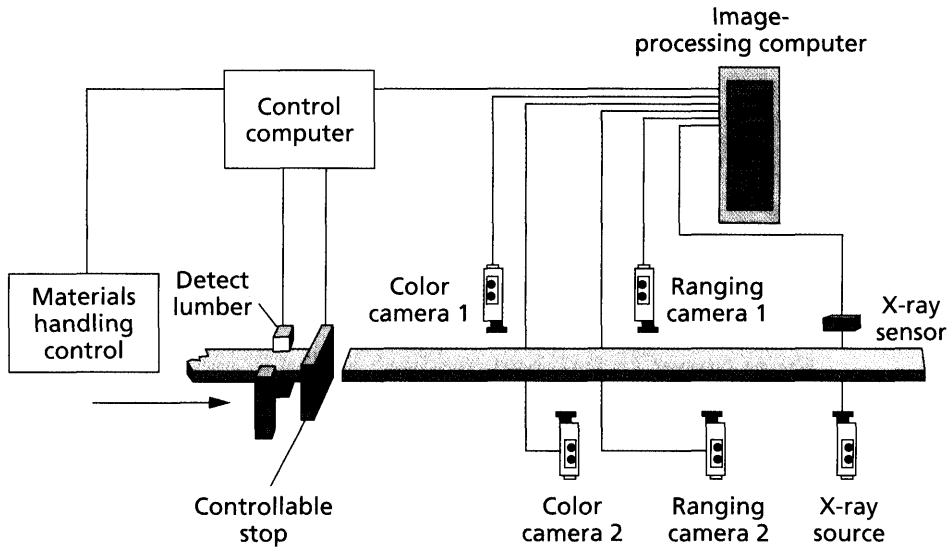

Figure 1. Schematic of the multisensor machine vision prototype for lumber inspection.

cannot detect the color of the wood or defects such as stains. Also, since some defects have nearly the same density as clear wood, they cannot detect all defects, nor can they accurately differentiate between defect types.

It is apparent that an ideal machine vision system would incorporate various sensing technologies, analyzing the combined data to locate and plot wood features and defects.

MULTISENSOR PROTOTYPE

Over the past 10 years, researchers at Virginia Tech have experimented with machine vision technologies for the forest products industry. Our work initially involved image-processing algorithms for lumber grading based on black-and-white and color imagery.[3,5] We have since gone on to experiment with multiple-sensing systems. By integrating information from color cameras and other sensors, we have developed a multisensory system suitable for a variety of manufacturing applications. Figure 1 shows a simple conceptualization of this system.

Our work has resulted in a multisensory machine vision prototype, pictured in Figure 2. This design includes

- a color-imaging system for locating and identifying surface defects and discolorations,
- a high-speed laser-ranging system for detecting cracks and holes in the surface and variations in the thickness of the board, and
- an X-ray imaging system for locating and identifying features associated with higher or lower density than clear wood.

The prototype integrates this sensing array with a materials handling system, an image-processing system, a control computer, and machine vision software.

The prototype is a full-scale machine that can handle the typical widths, thicknesses, and lengths of lumber. It can be configured for different types of sawmill operations and handle both green and dry lumber. It was built so that other sensing devices, besides the three described, can be added and tested. The prototype has been used to test various applications, including edging and trimming, lumber grading, color sorting, and automation of sawmill operations.[3,6]

The prototype meets all industrial requirements except that it does not provide a full range of speeds. Industrial processing speeds run from 120 to 1,200 linear feet per minute, but because of cost and safety concerns, the materials handling system on this prototype can achieve speeds of only 360 linear feet per minute. The effective speed of the prototype is lower, though, because the scanning system can only process data at a maximum 120 linear feet per minute (2 linear feet per second). This speed is adequate for hardwood applications, but would not be satisfactory for the inspection and processing of softwood lumber.

Color Imaging system

The prototype uses two Pulnix color line-scan cameras—one for each face of the board—having a resolution of 864 pixels and a data collection rate of 2.5 MHz.

The cameras were configured for a 13-1/2-inch field of view, which has been wide enough for the board specimens tested. With a processing speed of 2 linear feet per second, the cameras can produce color images with 64 pixels per inch cross-board resolution and 32 pixels per inch down-board resolution. This resolution is necessary to detect fine cracks and splits in the wood. With a crack-preserving filter applied to the data, however, the resolution can be later cut in half, allowing the data resolution to match that of the laser-ranging and X-ray sensing devices.

Tungsten-halogen incandescent bulbs illuminate the boards, with the light carried to the board surfaces through a bundle of fiber-optic cables. The ends of the cables are arrayed so that they shine a line of light across each board surface. The incandescent bulbs, then, can be mounted in a convenient location away from the board surfaces, keeping them away from the dusty wood and allowing easy replacement when bulbs burn out.

Figure 2. Multisensory lumber-scanning prototype.

Laser-based ranging system

The laser-based ranging system, designed and built at Virginia Tech, uses a 16-mW helium-neon gas laser with a 632.8-rim wavelength. A 24-facet polygon scan mirror, rotating at about 30,000 rpm, sweeps a point of laser light across the board. The image is captured by four EG&G black-and-white 128 x 128 array cameras at the rate of 384 frames per second. At 2 linear feet per second, the cameras have a data resolution of 32 pixels per inch cross-board and 16 pixels per inch down-board. Because the mirror is rotating so fast, sweeping the point of laser light across the board surface several times in one video frame, the cameras see a continuous laser line falling across the board.

The cameras then capture the displacement of the laser line and variations in its light intensity. This data, as an analog signal, is transferred to a special-purpose electronics board (which also provides a timing signal to the camera). The board converts the data to an 8-bit digital image, determines where the laser line is in each row of data, and then enters that pixel location into a lookup table. The table generates 7 bits of range data, which are transferred to a computer interface on the image-processing computer. Through this process, the laser-based ranging system can measure board thickness and voids and indentations in the board surface to within l/64th of an inch.

X-ray scanning system

The X-ray scanning system is much like those used to scan luggage in airports. The X-ray source's kilovoltage and beam current are both variable, with a maximum kilovoltage of 160 and a maximum beam current of 1 mA. The linear detector array that detects X-ray transmission through a board uses a scintillator and a photodiode to generate each pixel value. With the materials handling system moving boards at a rate of 2 linear feet per second, the imaging geometry of the system achieves a cross-board resolution of 32 pixels per inch and a down-board resolution of 16 pixels per inch.

Materials handling system

In order for these sensing devices to work properly, boards need to pass through the prototype at a constant rate, without bouncing vertically or shifting laterally. In this system, canted drive rollers beneath the board keep it moving, while pneumatic rollers above the board keep it in place. Canting the drive rollers keeps the board sliding snugly against a fence, which is critical for accurate image registration. The positioning accuracy of the material passing through the system is ±0.01 inch. A dedicated computer controls the system, which has programmable speeds ranging from 0 to 6 linear feet per second.

Image-processing system

The prototype's image-processing system is a 200-MHz Pentium PC with 64 Mbytes of main memory, running Windows NT. A single PC is not capable of executing the current vision algorithms in the four to eight seconds allowed for real-time operation because of the large amount of data in the collected images. For example, the color image data alone from both sides of a 16-foot, 13-1/2-inch board will require 32 Mbytes.

Part of this problem can be solved through parallel processing—having one PC process image data from the top of the board and another PC process data from the bottom. Another partial solution, which the prototype now incorporates, is the use of special-purpose electronics to perform low-level image-processing

A 286 PC controls the entire prototype system, sending control signals to the materials handling and image-processing computers.

functions. Low-level functions are simple sequential operations suitable for pipelined processing, such as repetitive operations on individual pixel values or groups of pixel values. In Virginia Tech's image-processing algorithms, these low-level functions require more than 70 percent of the computational time, so performance can be significantly improved by running them on special-purpose boards.

Therefore, the image-processing system uses the Morrph-ISA board, a modular and reconfigurable hardware processing board developed at Virginia Tech.[7,8] For computational units, the board uses field-programmable gate array chips. For each low-level image-processing task, the board creates specialized digital-processing units, which are connected using a synchronous bus standard to create systolic processing designs. These designs are then compiled into the gate-level resources of the FPGA chips. Being modular, the board needs only the required resources for the functions being performed.

The output from these low-level functions then needs to be passed on for high-level image-processing tasks, which involve complicated data structures and decision making. In order to keep this transfer from further slowing down the system, a high-performance direct memory access interface board (also developed at Virginia Tech) for the PCI bus transfers this information into system memory without using the system processor. Through this configuration, then, real-time processing of the large amounts of machine vision data is possible.

Control computer

A 286 PC controls the entire prototype system, sending control signals to the materials handling system computer and the image-processing system computer. The PC also continuously monitors the system components to ensure that they are operating correctly. At this point the software running the system is rudimentary, written in C and running under DOS, but it will be developed to include an interface so that a typical employee at a hardwood mill can use it to operate the system and perform routine maintenance.

Machine vision software

The software for the image-processing system was written in Visual C++ and consists of three algorithm modules:

- An *image preprocessing module* generates the images and histograms needed for further processing.
- An *image segmentation module* combines image data, performs segmentation functions, and extracts feature regions for further investigation.
- A *feature recognition module* uses domain-specific knowledge to identify feature regions that correspond to lumber defects.

Image preprocessing module. This module performs the following functions, implementing them in real time using the Morrph hardware:

- Performs shade correcting on the color and X-ray image data to remove nonuniformities in either illumination or detector sensitivity.
- Extracts a programmable field of view from the color, X-ray, and range image data. This reduces the amount of image data that is transferred. It also provides a method for compensating for misalignments between sensors.
- Determines the leading, lagging, right, and left boundaries of a board in all images. This further reduces the amount of data that must be processed and allows the histograms to be computed only from pixels that correspond to a board face.
- Averages the red, green, and blue channels of the color image data to create a new black-and-white image of the board.
- Halves the cross-board resolution of the color image data using a crack-preserving filter.
- Generates histograms of pixel values for the black-and-white and X-ray images.
- Outputs six registered images (red, green, blue, black-and-white, X-ray, and laser) and two histograms (black-and-white and X-ray).

Image segmentation module, Taking those images and histograms, this module does the following:

- Smooths the two histograms using a Gaussian filter.
- Establishes multiple image threshold levels, separating clear wood from features that might be defects. This thresholding is based on the fact that most of a board face is clear wood, and thus the largest peak in the histogram must be from that. A defect is indicated by an alteration of shape of the clear-wood peak and/or the existence of a smaller peak within the histogram.
- Uses connected component labeling to identify contiguous regions of interest with similar threshold levels. A defect, then, is a connected region that has similar gray-level characteristics.
- Extracts properties—size, geometry, location, color, density—for each region of interest. Each property is defined using inexact descriptive adjectives like *darker, lighter, redder, bigger,* and *rounder*. Because these terms are not exact, fuzzy logic is used.

Feature recognition module. This module uses technical data on wood features and patterns to identify regions of interest that affect the quality and value of lumber. The knowledge-based system uses rules to determine whether a region is a member of a particular defect class. Using fuzzy logic, the rules assign membership function values to the conjunctions and disjunctions in the basic set of adjectives used to represent region properties. For example, a simple rule for recognizing a knot would be: "A feature is a knot if it is redder than clear wood and is round."

Software efficiency. To handle the large amounts of data, the machine vision software processes data in a way that minimizes computational complexity and enhances feature-detection capabilities:

1. The segmented laser profile image is analyzed to determine which areas of the board fall above or below an acceptable thickness threshold. Areas that are too thin are then removed from consideration in subsequent analysis of X-ray and color image data.
2. X-ray data, along with color data, is used to locate knots, voids, and decay. These areas are removed from subsequent analysis.
3. By the time the color image data is analyzed, the larger and unambiguous defect regions have already been eliminated. Processing the data this way reduces computation time and makes it easier to analyze smaller defect regions in the histogram data.

Applications

Figure 3 shows the color image, the range image, and the X-ray image for the same board. Using these images, the software algorithm identifies feature regions and produces a table, or digital map, that lists the location and identity of all lumber grading features. Figure 3d is a graphical representation of that table, showing identified features as rectangles.

The data in the feature table can be used in a variety of applications, some of which have been developed independently of this project. One application takes the data, determines where the board should be edged and trimmed for maximum value, and automatically positions the edger and trimmer saw lines.[9] Another uses the data to automatically grade hardwood lumber.[10,11] A third demonstrates the potential for using the data in the manufacturing of dimension products from hardwood lumber.[12] Virginia Tech is now using these applications to both demonstrate the usefulness of the prototype and test its accuracy and performance.

Virginia Tech itself has developed two applications for its machine vision prototype, both now being patented. One addresses the growing use of edge-glued panels in the manufacturing of doors, tabletops, desktops, and other wood products. Because light-colored stains are becoming more popular, it is critical that the bare-wood colors of adjoining panels match. As a manual process, color sorting of wood is labor intensive and difficult, but this application, when used with the prototype system, can collect color data and automatically sort wood.

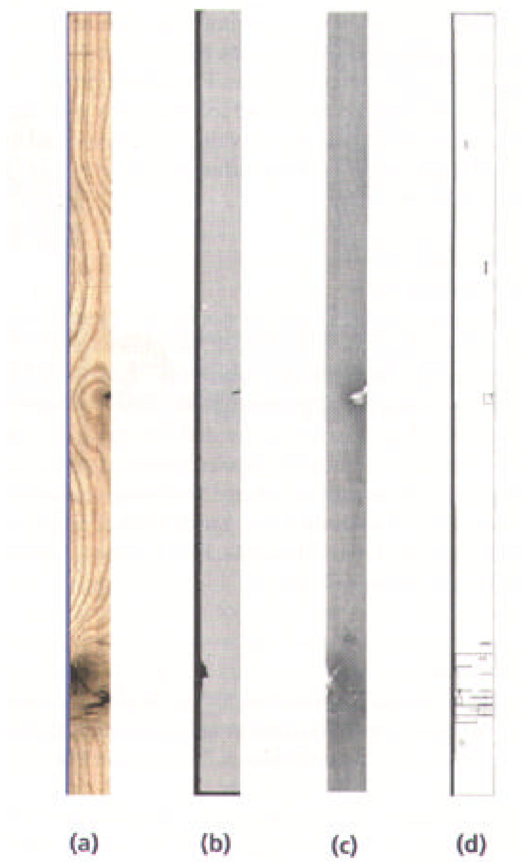

Figure 3. Illustration of multisensory machine vision results showing (a) color image, (b) laser-ranging image, (c) X-ray image, and (d) resulting defect map with rectangular feature areas identified.

Another Virginia Tech project applies this technology in rough mills where defects are removed with crosscut saws. This too requires a good deal of human attentiveness and energy to be done well. Researchers at Virginia Tech, however, have developed the hardware and software for the full-scale prototype system that will operate a fully automatic crosscut saw in a rough mill.

These applications show the usefulness of machine vision technology in the forest products industry. The labor-based techniques of today are little changed from sawmill practices of a hundred years

ago. Now, however, wood is more valuable and labor is more expensive. At the same time, technology has become more cost-effective. The development of machine vision hardware and software now provides the means to reap maximum value from wood and to make those working in the industry more effective in their jobs. ❖

Acknowledgments

We thank the US Forest Service for its long and continued support for this project, Virginia's Center of Innovative Technology, and the International Woodworking Fair. The Aristokraft Corp. and Sutton Woodworking Machinery funded the research that led to the development of these commercial products. We also thank our graduate students, including Chong Ng, Tai-Hoon Cho, Jason Hou, Qiang Lu, William King, Panes Arivanitis, Paul LaCasse, Lichun Guo, and Xiangyu Xiao.

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