

Locating knots by industrial tomography— A feasibility study

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Abstract

Industrial photon tomography was used to scan four southern pine logs and one red oak log. The logs were scanned at 16 cross-sectional slice planes located 1 centimeter apart along their longitudinal axes. Tomographic reconstructions were made from the scan data collected at these slice planes, and a cursory image analysis technique was developed to locate the log perimeter and identify and locate internal knots from the reconstructed tomographic images. After scanning, the logs were cut into 1-centimeter-wide cross sections (width included saw kerf) which corresponded to the scan slice planes. It was found that the log perimeters and knot locations identified through the image analysis of the tomograms compared favorably to those same entities found on the actual log slices.

Continued research to increase the speed of tomographic detection of defects and develop sawing decision algorithms is encouraged by the study results. Commercialization of the decisionmaking process for increasing the grade of processed lumber could increase the utility of the timber supply.

Presently, most logs are processed into lumber with little information about the log or the potential grade and volume of lumber obtainable from the log. These logs are sawn by an experienced sawyer who uses only his best judgment in positioning each log for making individual saw cuts. Sometimes the sawyer unknowingly chooses the best possible sawing pattern for a log. However, many times his choices are far from optimal and less lumber or lumber of lower grade is produced.

In recent years, optical scanners coupled to computers have been used to obtain information on log geometry. This information is used in computer algorithms to select sawing patterns and log orientations that maximize the volume of lumber sawn from each log. In some cases, the sawing process itself is computer controlled through an interface system.

If, in addition to scanning logs for geometry, the extent and location of defects within logs were known, even more accurate sawing decisions could be made. Such information would not improve volume yield, but grade yield could be appreciably increased. A number of studies have indicated that the value of lumber sawn from a given set of logs could be increased by as much as 7 or 8 percent if the locations of internal log defects were considered in the log sawing decisions (10, 11, 13, 14).

Objective

The objective of this study was to investigate the practicality of using industrial tomography and automatic image analysis to nondestructively identify and locate internal knots within freshly sawn logs. Prior to the study, it was known that areas of widely different density, such as decay and embedded metal, could be readily detected within wood (2, 12). However, tomographic detection of knots is more difficult because the

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Forest Prod. J. 34(5):42-46.

density of knot tissue is not greatly different than that of stem tissue. Detection of knots is especially difficult in freshly sawn logs where water tends to mask the location of knots. It was reasoned that if industrial tomography and automatic image analysis could be used to identify and locate knots within freshly sawn logs and if scanning could be performed at a rate compatible with log conveyance speeds within sawmills, commercial tomographic log scanners could eventually be developed for sawmill use.

Background and related studies

Research has shown that log orientation with respect to saws can affect both lumber grade and value when internal defects are considered in sawing decisions. In a study involving simulated sawing of southern pine logs, Wagner and Taylor (14) found that the average value of lumber obtainable from a log could be improved by 7 percent by selecting the optimum log rotation. They also found that the volume of No. 1 and No. 2 grade dimension lumber could be increased by 12.7 percent if the locations of internal knots are considered. Other studies of log sawing (10, 11, 13) indicate that log orientation with respect to defect placement is important to the grade and value of lumber sawn from hardwood logs. Richards (10) states that defect placement is the single most important decision a sawyer makes in positioning the log for initial cut.

A technique known as computed axial tomography (CAT) has become widely recognized because of its use in medical imaging (9). Since its commercial introduction just 12 years ago, CAT has become the traditional method of obtaining three-dimensional information on patients and is used in every major hospital within the United States (3).

The product of a CAT scan is a two-dimensional image of the photon opacities (or densities) of an object in a cross-sectional plane. The two-dimensional image, called a tomogram, is computer calculated from measurements of the photon projections of the object at many angles through a slice plane. Although each set of measurements consists of several projections in which all of the opacities along a line are added together, the computed tomogram is not a projection. Rather, it is a reconstructed image of a cross section of an object. This is what distinguishes tomography from ordinary radiography (4).

The use of an industrial version of the CAT scanning technique has been described (2, 5, 8). Industrial photon tomography utilizes a gamma ray source which is collimated to form a flat fan of rays that project through an object to a set of detectors. Either the object or the source-detector apparatus is rotated to give a series of projections through the same plane to produce the tomogram. It is possible to produce a number of closely spaced tomograms over the length of an object and thus accurately locate density differences within an object in three dimensions. To date, industrial tomography has been used to scan a variety of materials including concrete, metal, plastic, and wood (2, 5, 7).

In a study involving the examination of wood power poles (12), industrial tomography was shown to be an

accurate method of evaluating poles for internal defects. The study reported that tomograms showed knots, growth rings, surface cracks, interior worm holes, decay, and preservatives within poles.

Systematic methods for the evaluation of tomograms from logs have been proposed (4, 6). McMillin suggested the use of gray level thresholding as an analysis technique. Using an automatic image analyzer and a tomogram made from a 9-inch-diameter southern pine log, the technique revealed the cross-sectional area of the log, the center coordinates of the log, and the size and coordinates of a knot. Hopkins, Morgan, Ellinger, and Klinksiek suggest the use of isodensity markings, scale selection, image subtraction, histograms, frame analysis, trace analysis, and pattern recognition as viable techniques for the analysis of tomograms. Their work has indicated that the pattern recognition approach may hold the key to a fully systematic method for the analysis of tomograms to identify and locate knots within logs.

Procedure

The procedure involved removal of stem sections containing knot whorls from selected trees. Since the effect of moisture (particularly moisture content variations) was a potential source of error, the sections were kept green until measurements were complete. Sections were scanned respectively through the knot whorl. Then, they were sawn along the plane of the scans. Scan information was compared with defect locations determined from sawn sections, and potential machine recognition procedure was demonstrated.

Four 1-foot-long southern pine log sections and one 1-foot-long red oak log section were selected for the study. All log sections were freshly cut from loblolly pine trees. The sections were hand peeled and a 1/2-inch-deep saw kerf was made along one side. The saw kerf ran longitudinally from end to end of the section and represented the zero degree orientation. All sections were sprayed with a sodium pentachlorophenate solution and sealed in plastic bags to reduce fungal growth and retard moisture loss.

Because knots are the most common grade-reducing defect encountered in pine logs and lumber, and, in an attempt to reduce the scope of this study, knots were the only internal log defects considered. Log sections were, however, selected to contain wood variables that could confuse the tomographic image analysis identification of knots. Log sections were individually selected to contain compression wood (log 1), resin streaks (log 2), irregular perimeter shape (log 3), and high-density wood (log 4). Log sections were approximately 12 inches in diameter and represented normal growth rate (except log 4 which was slow grown).

A tomographic scanning system provided by Scientific Measurement Systems, Inc., Austin, Tex., was used for the study. Detectors were configured to yield a ray spacing of 0.1 or 0.2 inch at the center of the projections. All log sections received 100 projections at each cross-sectional slice plane, and slice planes were configured 1 centimeter apart along the longitudinal axis of the log

section. Sixteen slice planes, encompassing the central 6-inch portion of each log section, were scanned. The scanner photon source was Ir 192.

Log section No. 3 was used in a preliminary test to determine exposure per projection (in Curie-sec.) needed to generate sufficient data for tomogram reconstruction. Exposures of 200, 20, 2, and 0.2 Curie-seconds (corresponding to exposures of 1, 0.1, 0.01 and 0.001 sec. for the 200-Curie source) were tested using 100 projections per slice plane and reconstructed into tomograms. Visual inspection of the full set of 16 tomograms for each exposure rate indicated that 2 Curie-seconds (or 0.01 sec.) produced images of sufficient resolution for analysis purposes. Longer exposures produced higher quality tomograms but at a scan speed judged too slow to be acceptable. Figure 1 shows a tomogram of a slice plane from log section No. 3 reconstructed from projection data at the 0.01-second exposure rate.

The central 6-inch section of each of the remaining four log sections was scanned at the 0.01 second exposure rate and the scan data was reconstructed into tomograms.

After scanning, the central 6-inch portion of each log section was cut into 1-centimeter-wide cross sections (width includes saw kerf) which corresponded to the

scanned slice planes. The top of each slice was photographed, and the perimeter and location of knots present in each slice were traced onto paper. Photographs were also made of all reconstructed tomograms displayed on the CRT. All photographs were approximately one-half actual log size.

A cursory image analysis technique was developed to demonstrate the technical practicality of automatic log perimeter and knot detection. Since dark colored areas of the tomograms represent either background or areas of low density, and light colored areas represent areas of high density, the image analysis technique was based on gray level thresholding (6). The tomographic image was divided into a 24 by 24 array of 1/4-inch areas. The percentage of black was then measured for each area. Background areas were always 99 to 100 percent black, and high-density wood was near zero percent black. The interface between background and wood, areas containing knots of low density, and areas of juvenile wood had intermediate values.

A computer program was written to execute the analysis for locating knots and log perimeters from these data. Since background areas always measured 99 to 100 percent black, these areas were deleted from the array. The perimeter was then located as the first non-zero value encountered by searching the data array

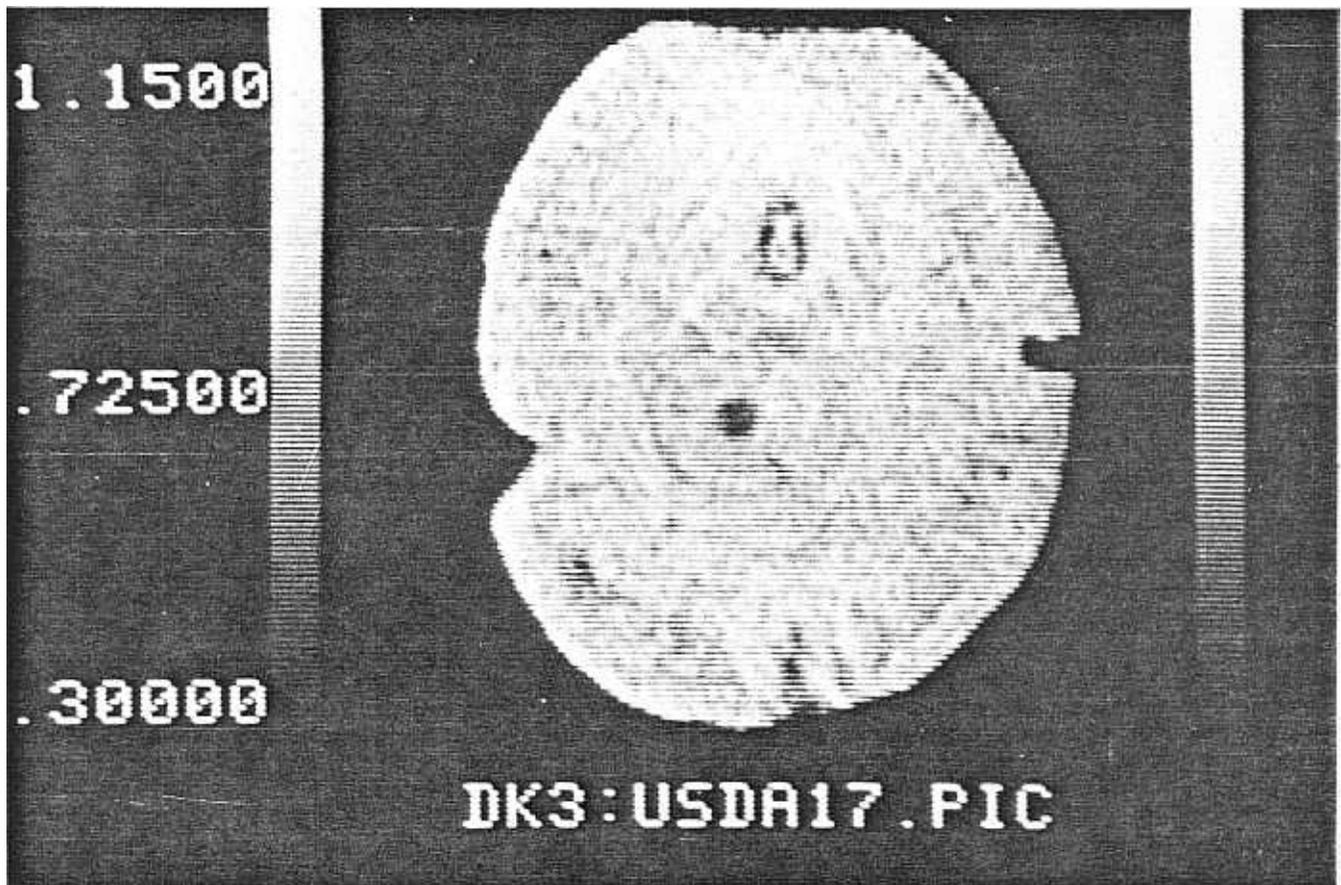


Figure 1 Tomogram of a slice plane constructed from scan data at the 0.01-second exposure rate. The gray-level scale indicates specific gravity.

along the x-axis, first left to right and then right to left. The coordinates of the perimeter areas were recorded and the values deleted from the data array. Values for juvenile wood and other areas of low density near the geometric center of the tomographic image were also deleted. What remained were areas of low density knots which were located by scanning the array for values greater than zero. A similar scanning process was used to analyze tomograms containing knots of high density by measuring area percentages below a preselected white threshold.

Results

Results of the study suggest that a systematic image analysis technique can be developed to identify and locate knots and log perimeters from tomographic images. Figure 2 shows a tomogram, an image analysis of the tomogram, and a photograph of log 2. The numbers in the image analysis output show values for percent area black summed with percent area white. Background values and values for juvenile wood have been deleted. Note that the size and shape of the log and the location of all knots visible on the tomogram and cross section photograph were detected in the image analysis output.

Water present in green logs and the lack of large density differences between the knots and the surrounding wood tissue make knot identification and location by this method more difficult. Image analysis of the tomograms showed that all knots were currently identified and located in logs 1 and 2. In logs 3, 4, and 5, most knots were correctly identified and located but some errors did result. The magnitude of the errors varied from log to log. In a few cases, the image analysis technique failed to identify knots that could affect the grade of sawn lumber.

Discussion

Experience gained in this study encourages the researchers to believe that tomography and automatic image analysis techniques could be used to detect log perimeters and internal knots. One weakness of the technique employed in this study was that photographs of the tomograms were used. Both the number of gray-scale levels and clarity of the tomographic image were reduced through the photographic process. It is believed that better image analysis results could have been obtained had the raw data representing the tomograms been used in a similar analysis. This belief is based on the fact that knots can be visually recognized on tomograms. Knots located on tracings were, in fact, always detectable by researchers looking at tomograms.

The speed at which logs can be scanned using computed axial tomography was a concern in evaluating the practicality of the technique. Medical CAT scanners, which utilize x-ray sources, are much slower than would be practical for sawmill operations (1). Several minutes of scanning and computational time are usually required to produce a medical tomographic image. However, this study indicates that the scanning can proceed much more quickly. The industrial tomographic scanner used in this study produced acceptable projection data at the 2 Curie-second exposure rate. With an Ir 192

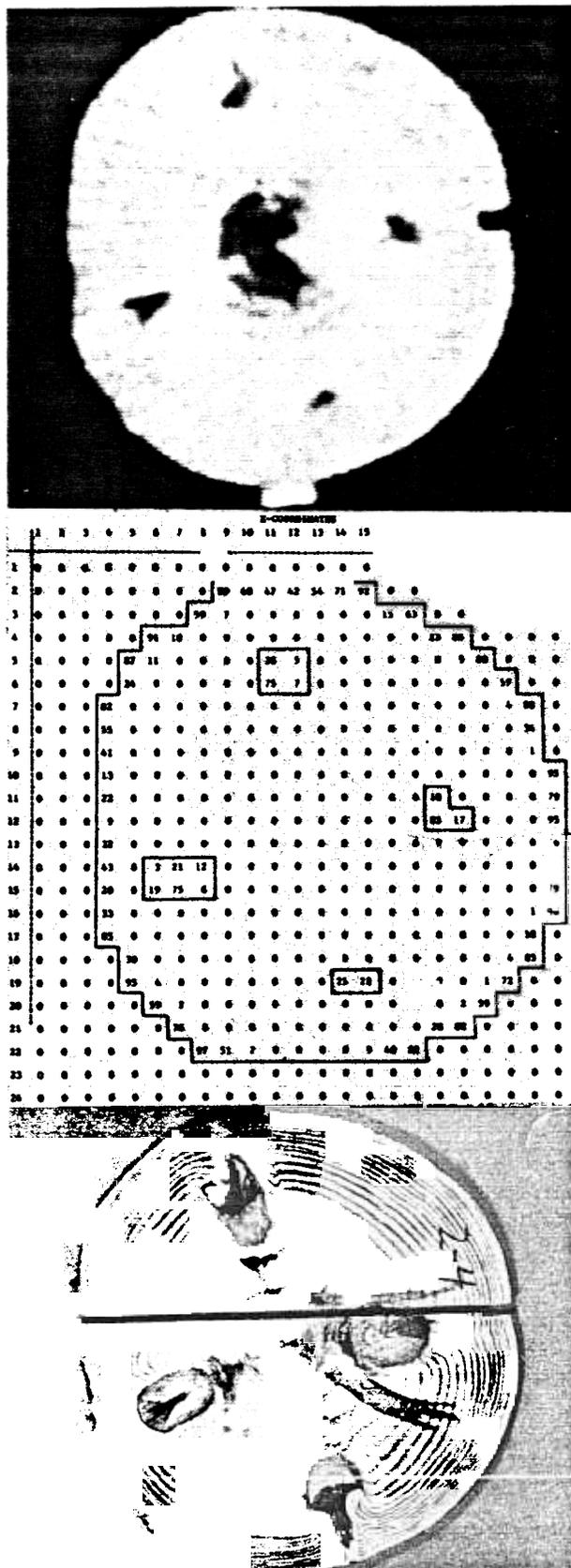


Figure 2. — Slice plane from bolt 2 represented by (top) a tomogram, (center) an image analysis of the tomogram, and (bottom) a photograph of the bolt cross section (the horizontal space is a saw kerf resulting from splitting the bolt before sawing discs).

source, this translates to 0.01 for each projection. Thus, data needed for a tomogram reconstructed from 100 projections in one slice plane could be collected in about 1 second. Although the 1-second data collection rate is still slower than would be acceptable at many sawmills, the speed is fast enough to encourage research to adapt scanning technology to the log sawing process.

In a high-production sawmill, the log transfer rate may be as high as 3 feet per second. If logs moving at this speed were scanned at the 1-second scan rate, enough data could be collected to reconstruct only one tomogram each 3 feet along the longitudinal axis of the logs. To assure that significant grade defects are not missed, it would probably be necessary to collect data at 1-inch rather than at 3-foot intervals. This may be accomplished by the following suggested methods: 1) Logs could be selected by size and surface defects for scanning. Previous studies show that some logs have a higher potential for lumber grade recovery improvement than do other logs (9, 10, 12, 13). Such logs could be selected from the process stream and scanned at a rate slower than 3 feet per second. 2) A cursory scanning technique could be developed and employed that collects and processes data from only a few projections rather than from the 100 projections needed for reconstructing a full tomogram. The technique would be used to indicate the potential presence of defects within each slice plane. If defects are indicated, a full tomographic scan could be performed to identify and locate defects in that slice plane. If no defect is detected, cursory scanning would be continued at the next slice plane.

Conclusions

Computed axial tomography holds promise for nondestructive detection of interior log defects. This study demonstrated that knots within green logs are visible in tomographic images and can be identified and located by computer methods. The study also indicates that the rate at which scan data can be collected may be increased to a level practical for making computer assisted processing decisions. The basic data for knot recognition is available in the tomograms and in the projection data used to reconstruct the tomograms. It seems possible that a reliable technique for the machine recognition of knots from tomograms or from projection data may be developed. The recognition of knots from projection data would have the added advantage of requiring fewer scan angles and less scanning time than would be required for the recognition from reconstructed tomographic data.

In addition to the development of a fast and reliable method for the recognition of knots, algorithms for determining the proper sawing pattern and log orientation must also be developed. These algorithms would use log geometry and knot location information to select the sawing pattern and log orientation that would produce the highest value lumber from each log.

The commercial installation of a scanning system in a sawmill also requires other developments. Scanner and computer equipment must be designed to withstand the sawmill environment. Log transport systems to pass logs through the scanner with little side motion, rotation, or vibration are needed. The hardware to translate log rotation decisions into visible log markings or to physically position logs for processing must be designed.

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