Application of Automatic Image Analysis to Wood Science

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ABSTRACT. In this paper I describe an image analysis system and illustrate with examples the application of automatic quantitative measurement to wood science. Automatic image analysis, a powerful and relatively new technology, uses optical, video, electronic, and computer components to rapidly derive information from images with minimal operator interaction. Such instruments should prove useful to researchers and technologists who use analytical procedures, inspection methods, and investigative techniques that require processing large amounts of data (e.g., fiber length and cellular dimension measurements). Additionally, a system using scanning technology for primary log breakdown and for cutting clear furniture parts from defective boards is proposed. In the system, computerized axial tomography — known popularly as CAT scan — nondestructively locates defects within log interiors. A computer program then positions the log to yield boards of maximum value. Optical scanning methods identify and locate defects on board surfaces. The defect data is used to compute complex cutting patterns to maximize yield of clear pieces using a laser-cutting device.

MANY TECHNIQUES USED in wood science require a researcher to recognize, differentiate, and quantify large amounts of data from images. In some cases many hundreds or thousands of measurements may be needed. This can be a repetitive, fatiguing, and time-consuming process.

Automatic image analysis, a relatively new technology, employs optical, video, electronic, and computer components to perform the operations and process the information from images with minimal user interaction. While the technology has been extensively used in the fields of metallurgy, medicine, and biology, few applications have been reported in wood science and the wood industry.

In this paper I briefly describe one type of image analysis system and illustrate by examples the use of automatic quantitative measurement in wood science.

Image Analysis System

A general view of the equipment used is shown in Figure 1. The image analyzer in the center of the photograph consists of an operator's console with video display and keyboard, minicomputer with 64K memory, two 8-inch floppy disks for program and data storage, and signal detection and conditioning equipment. A terminal for programing and for printing data is located to the right of the photograph. The image scanner is located to the left and is shown attached to a macroviewer.

Figure 2 gives a block diagram of the main system components. The first step in the analysis chain is that of imaging. In this system, images may be obtained through a microscope or directly from specimens or photographs (including electron micrographs) using an illuminated macroviewer. Thus, a

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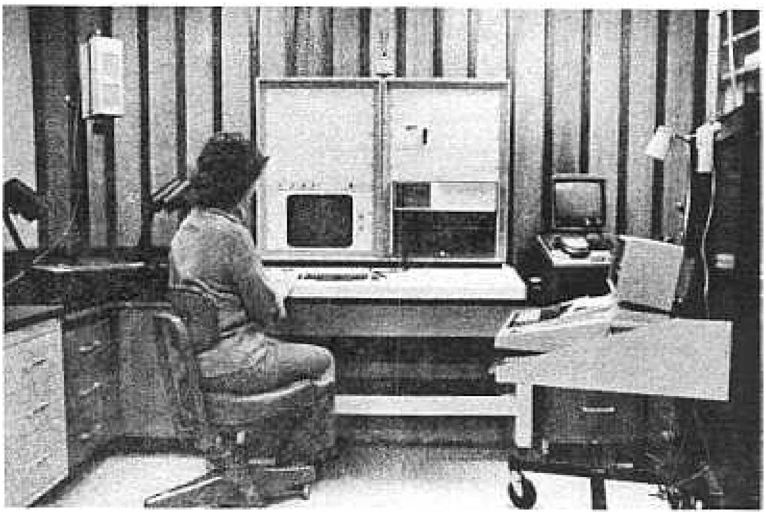


Figure 1. — General view of the image analysis laboratory.

wide range of imaging techniques is available over a broad range of magnifications (X0.3 to X20,000).

In the next step, the image is focused on the photosensitive area of a scanner unit, similar in design to a video camera. The image is scanned along parallel lines to produce a video signal (as a function of position) proportional to darkness (gray level) along each line. The resulting image may be saved for records or for subsequent analyses by photographing the television monitor, recording the signal on video tape, or by storage of the digital image on disk.

The analog video signal is then directed to the operator's console and displayed on the monitor. Threshold controls are adjusted, based on gray level, to detect selected portions of the image for measurement. Detected portions can be displayed as intense white areas. Concurrently, the signal is converted by binary code and sent to the processor. These data are manipulated by software programs to yield measurements preselected by the operator.

The image can be processed in two ways. In the first mode, data are manipulated in the processor by user-written programs. Any desired combination of measurements can be made from the stored data. In the second and faster mode, the operator simply chooses from a menu of 13 basic measurements. A few are illustrated in Figure 3. In either mode of operation, the basic measurements can be used to derive a variety of size and shape factors. For example, the ratio of area to longest dimension yields the average feature width at right angl to the longest dimension.

The final stage of analysis is data proces ing. This may take the form of a listing (measurements, distribution histograms, (statistical analyses. The results can be di played on the monitor or printed.

Two other pieces of equipment complete tl system. A shading corrector provides increase resolution of gray tones by compensating f(optical distortion and nonuniform illumin tion. An image modifier module and associat software permit operator-controlled editing (the displayed video image (i.e., deleting u wanted portions of the image, separati touching features, filling poorly detected area etc.).

In practice, the operator obtains an ima at an appropriate magnification and initiates software program to calibrate the syste Threshold controls are then adjusted to tl desired detection level and a series of keyboa commands used to instruct the computer as what type of measurements are to be made a the form of the analysis. If required, the ima may be edited using the image modifier lig pen. The operator then issues a single k command to measure all detected features in preselected field of view.

Automatic image analyzers are compl machines and many special features a operational details of the author's system ha been omitted as beyond the intent and scope this discussion.

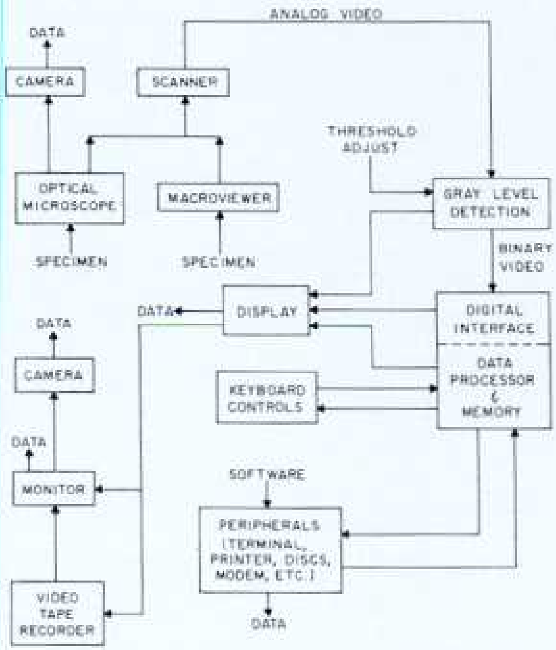


Figure 2. — Block diagram of the image analysis system used by the author.

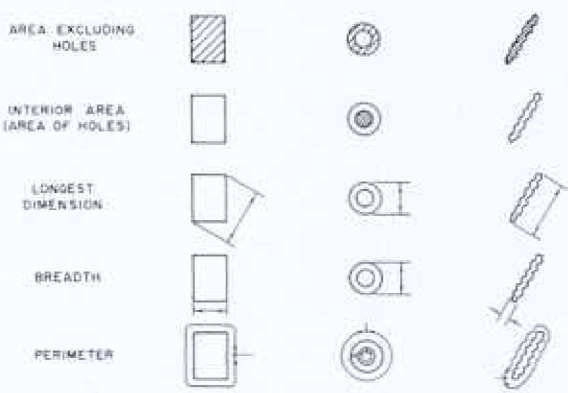


Figure 3. — Illustrative image analysis measurements for selected geometric shapes.

Applications

The following are a few areas where applications of automated image analysis have been made.

Fundamental Properties
- Dimensional stability
- Failure Mechanisms

Pollution
- Particulate sizing
- Particulate counting

Quality Control
- Sizing parts
- Defect detection

Machining
- Surface roughness
- Knife wear

Composite Products
- Particle geometry
- Particle orientation

Wood Properties
- Growth rate
- Proportion latewood

Pulp and Paper
- Fiber geometry and shape
- Dirt in paper

Anatomy
- Cellular dimensions
- Cell type proportions

Preservation
- Decay detection
- Treatment effectiveness

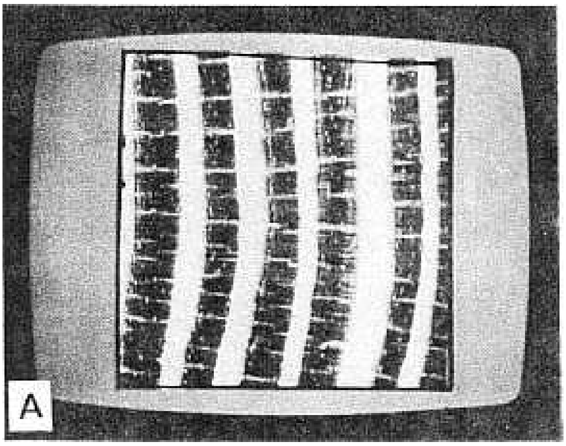
Plywood
- Percent wood failure
- Check depth and frequency

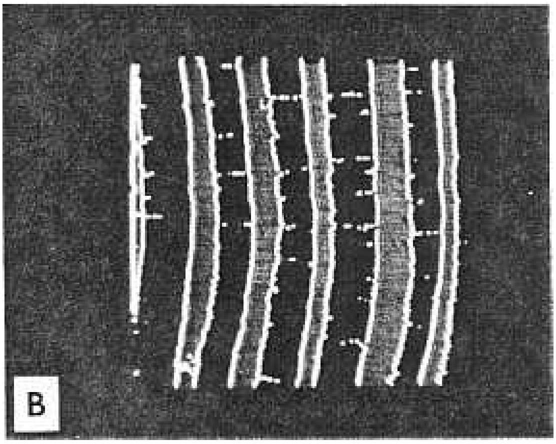
The following discussion is intended to provide the reader with some illustrative examples.

Proportion of Tissue Type and Growth Rate

For this example, the transverse surface of a cube of loblolly pine was sanded with successively finer sandpaper until the growth increments were clearly visible. Figure 4-A shows the video image displayed on the monitor. The dark bands are latewood while the lighter bands are earlywood. The black vertical and horizontal lines surrounding the specimen delineate the field of examination and are selectable by the operator — i.e., areas outside the lines are excluded from the analysis. The area of the full field was determined to be 1.54 square inches.

The threshold was set to detect the dark latewood bands. The white lines in Figure 4-B delineate the detected separation of the tissue





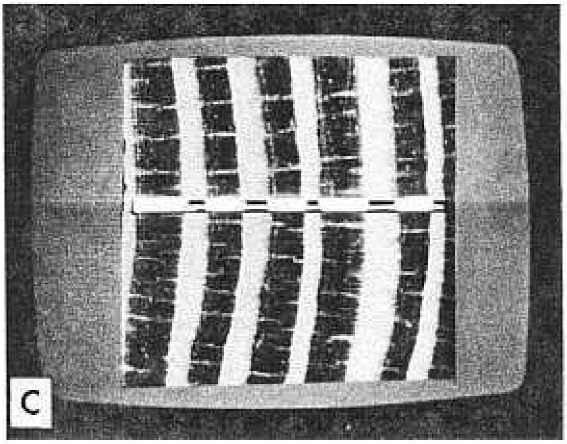


Figure 4. — Analysis for gross wood properties — A) video image and field definition, B) detected earlywood-latewood interface, and C) narrow partial field and detected latewood bands.

types. The ratio of the detected area (latewood) to the area of the full field was measured to yield proportion latewood. The average width of latewood was derived by dividing the area of latewood bands by their vertical heights (excluding the latewood band to the right of the field). The threshold was then set to detect the light earlywood bands and the measurement repeated — the earlywood band to the left was excluded in this measurement. Findings are shown in Table 1.

Growth rate was measured by establishing a narrow horizontal partial field extending from the beginning of a latewood band to the end of an earlywood band (Fig. 4-C). After measuring the longest dimension of the full field, the controls were adjusted to detect latewood bands (the white areas in the field of Fig. 4-C). Growth rate was measured by dividing the number of bands by the full-field longest dimension. The result was 4.27 rings per inch of radial growth.

TABLE 1. *Proportion of tissue type and band width.*

	Tissue type	
Measurement and statistic	Latewood	Earlywood
Area proportion	0.65	0.35
Band width (in.)		
Minimum	0.11	0.06
Maximum	0.17	0.12
Avg.	0.14	0.08

Fiber Length

A small sample of loblolly pine was macerated in a 50/50 mixture of glacial acetic acid and 30 percent hydrogen peroxide and

TABLE 2. — *Summary of sample data collected by two methods.*

Statistic	Fiber length (mm)	
	Machine	Manual

dyed with a 2.5 percent solution of Chlorazo Black. After dilution in water, a few tracheids were transferred to a glass slide and separated by hand to eliminate those touching or crossed. (While adequate for the present purpose, this procedure would not prove useful where a large number of measurements are required.) The macroviewer with transmitted illumination was used for imaging at X5 magnification.

The perimeters of eight fibers were detected as a series of white dots on the video image (Fig. 5-A). For this measurement, fiber length was considered equivalent to one-half the perimeter. Each fiber was measured separately and the result printed with the fiber location in the field of view noted. A photographic enlargement of the video display permitted measurement of individual fibers by manual methods. This procedure was repeated for fibers on additional slides.

A statistical summary for the machine and manual methods is given in Table 2.

A plot of fiber length by manual measurement (horizontal axis) versus fiber length by machine measurement (vertical axis)[1] is shown in Figure 5-B. A linear regression analysis yielded the following: $Y = 1.0613(X) - 2.705$; $R^2 = 0.96$; std. dev. = 0.13 mm; F-ratio = 490. While the foregoing regression analysis is admittedly based on a very small sample, the relationship is significant and the correlation is excellent.

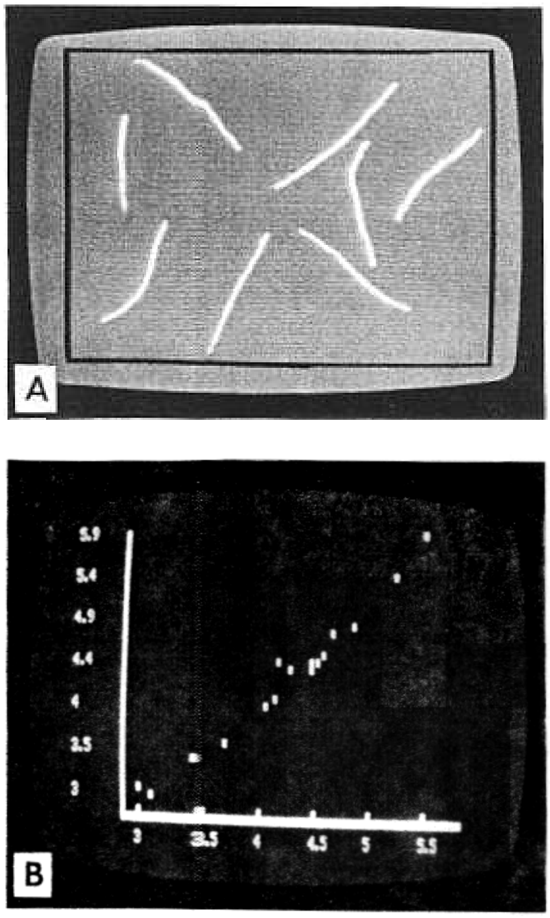


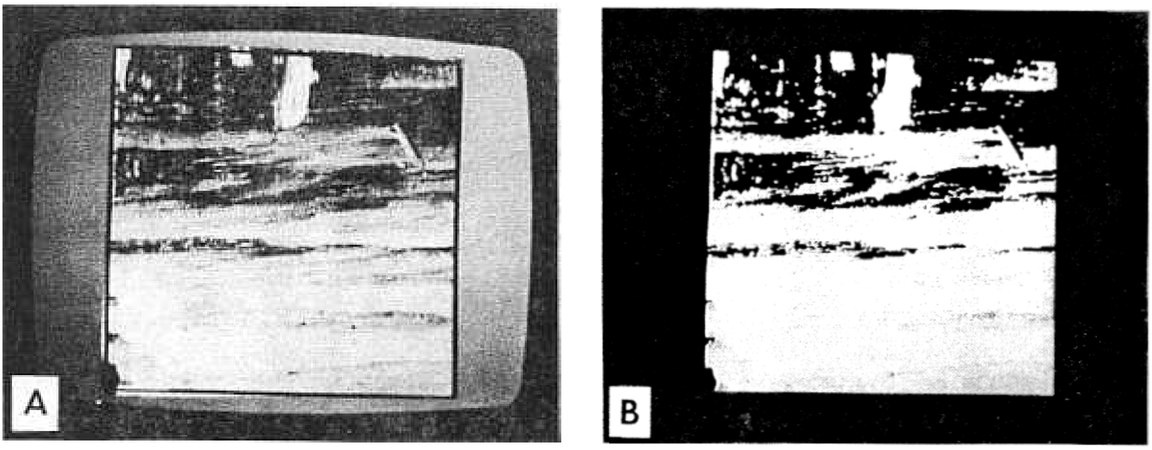
Figure 5. — Analysis for fiber length — A) video image of detected fibers, and B) video graphics display of manual (X-axis) vs. machine method (Y-axis) of measurement.[1]

Percent Wood Failure in Plywood Shear

Figure 6-A shows the video image of the failure surface with the field of analysis defined by the dark vertical and horizontal lines. All or only part of the entire field may be examined and evaluated simply by moving the boundary lines. The area of the field was 0.992 square inch. The threshold level was then adjusted to detect the lighter portions of the image representing wood failure (Fig. 6-B). The ratio of the white area to total field area is the proportion of wood failure and was measured as 72.7 percent. The surface was judged as 70 percent wood failure by independent visual evaluation.

Additional information can be obtained from measurements on selected areas. As an example, the field was adjusted to include only the lower left quarter of the failure surface (Fig. 6-C). Percent wood failure was measured and the field moved to include only the lower right quarter. The procedure was then repeated for

[1]The video graphics display in Figures 5-B and 7-D are not part of the image analysis system but were developed on the author's personal computer system.



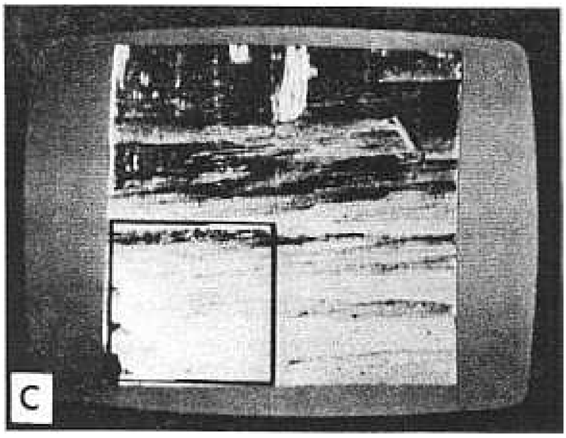


Figure 6. — Analysis for percent wood failure ir plywood shear specimen — A) video image of failur surface, B) video image of detected wood failure, anc C) image of partial field for selective are measurements.

the upper two quadrants. The results were (quadrant: wood failure (%)): upper left: 45.8 — upper right: 49.5 — lower left: 95.8 — lower right: 97.7. Most wood failure occurred in the lower half of the failure surface and there was little difference between the left and right halves. Differences in amounts of wood failure in the different quadrants can help in determining reasons for overall wood failure.

Void Volume, Lumen Area, and Radial Lumen Diameter

For this final example, a transverse microtome section of shortleaf pine was prepared and stained dark red. A research microscope (interfaced with the scanner) was used for imaging the section. Figure 7-A shows the video image of a group of latewood tracheids radially aligned in the horizontal direction. The middle lamellae appear as dark areas betwee cells, cell walls are gray, and lumens ar displayed white. Three measurements wer selected for analysis in both earlywood and i latewood — void volume, area of lumens, an radial lumen diameter. The data given here ar specific to the one section measured and are no representative of the species.

Void volume was derived by detectin lumens in a large field and measuring the are percentage averaged over several sampl locations. The results are given in Table 3.

Lumen area was measured by creating partial field positioned along a radial row o cells so as to include only complete lumen (center group of cells in Fig. 7-B). Afte measurement of individual lumen areas, th field was moved to an adjacent radial row an additional area measurements summed int

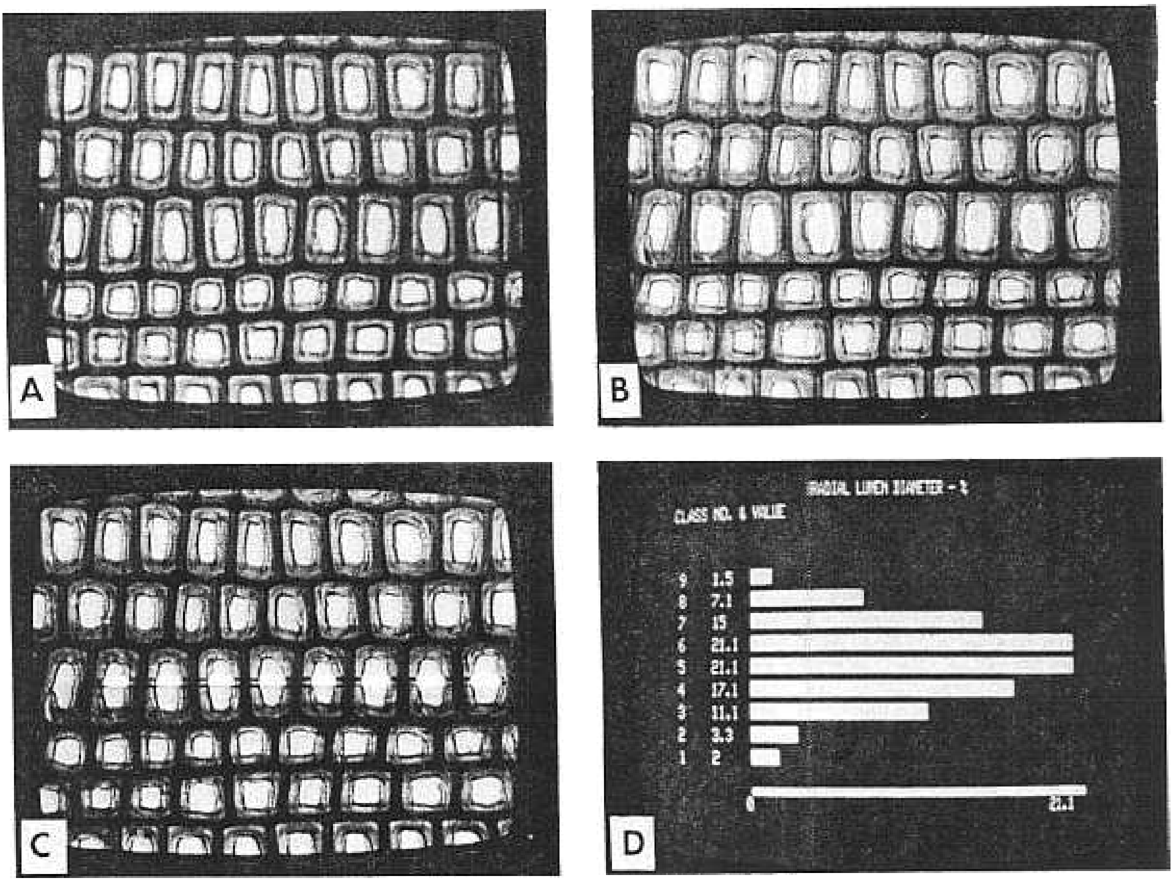


Figure 7. — Analysis for void volume, lumen area, and radial lumen diameter — A) video image of transverse section in large field, B) video image using partial field for area measurement, C) video image of narrow field used for radial diameter measurement, and D) video graphics histogram of radial lumen diameter.[1]

TABLE 3. *Sample data used in determining void volume of tissues.*

Measurement	Tissue type: Earlywood	Latewood
	230	275
	60.4	14.3

computer memory. The procedure was then repeated for different areas of the specimen.

Radial lumen diameter was measured by establishing a narrow partial field positioned in a radial direction (as in the center of Fig. 7-C — the width of the field in the figure is exaggerated for illustrative purposes). The threshold was adjusted to detect lumens (white areas within the narrow field) and the longest dimension measured. The field was then moved to an adjacent radial row and additional data were summed into memory. The procedure was repeated for different areas of the specimen. Results of the analyses are given in Table 4.

The data obtained for lumen area and radial diameter may also be presented as distribution histograms. For example, Figure 7-D shows the linear distribution histogram of earlywood radial lumen diameter.[1] The lower limit of Class 1 was 15 μm and the class limits were 3 μm. The data values listed are percentages of the total number of observations. The histogram shows the distribution to be reasonably normal with almost one-half (42.2%)

TABLE 4. — *Sample data from lumen measurements and statistics calculated.*

Statistic	Lumen area		Radial lumen diameter	
	Earlywood	Latewood	Earlywood	Latewood
	(sq. μm)		(sq. μm)	
No. of cells	411	475	500	484
Minimum	172.3	11.6	15.7	5.2
Maximum	1,307.6	233.8	40.6	18.1
Mean	659.8	102.8	29.2	8.9
Median	641.0	98.3	29.3	8.7
Standard deviation	232.3	53.8	4.9	2.3

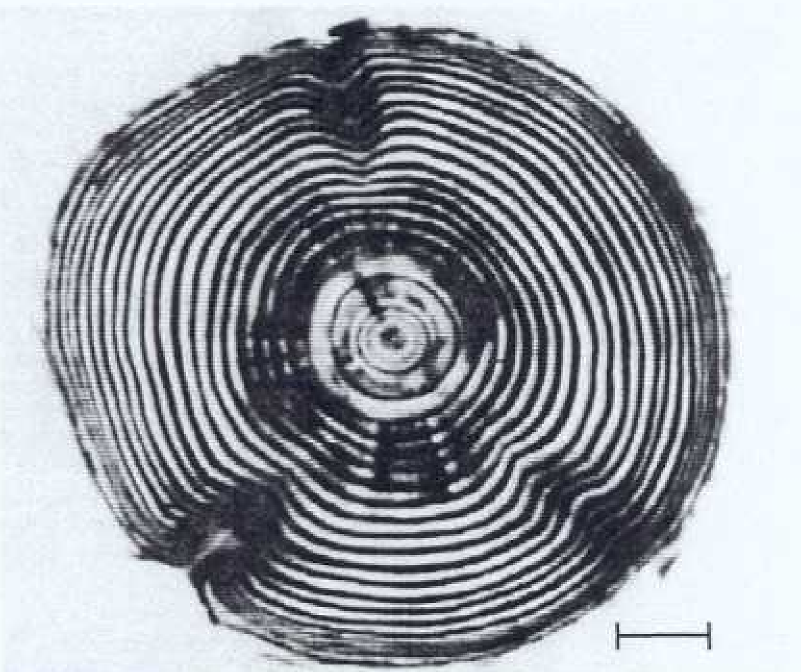


Figure 8. — Computer tomograph of southern pine log cross section. The scale mark shows 1 inch.

of radial lumen diameters between 27 and 33 μm.

It is significant to note that the foregoing analysis involved a total of 2,375 observations and was completed in less than 2 hours. A similar analysis by manual means might require several weeks.

Proposed Cutting System Using Scanning Technology

In the foregoing examples, quantitative data were obtained from static images. It is likely that scanning techniques and image analysis methods will also be used in real-time applications.

For example, scanners are now used to obtain information on log geometry. These data are then computer processed to provide the sawyer with information to position the setworks. If, in addition to scanning for log geometry, the extent and location of defects within the log could be assessed prior to breakdown, even more accurate sawing decisions could be made.

The interior characteristics of logs can be nondestructively determined by a scanning technique termed computerized axial tomography. Simply stated, a photon source is scanned perpendicular to the longitudinal axis of the log while detectors opposite the source

TABLE 5. — *Sample data collected from an analysis of a log using scanning technology.*

Measurement	Full log section	Knot
Maximum diameter (in.)	9.5	1.9
Minimum diameter (in.)	8.7	1.1
Area (in.^{2})	62.9	1.6
X-coordinate	9.6	6.9
Y-coordinate	5.7	8.1
Growth rate (rings per in.)	5.2	—

[1]Diameter and area measurements are outside the bark. The *X* and *Y* coordinates given are at the center of a rectangular box formed by two horizontal and two vertical lines tangent to the feature and are with respect to an arbitrary origin located in the upper left corner of the tomograph (Fig. 8).

receive the attenuated signal. The source-detector assembly (or the log) is then rotated to additional radial positions to yield a series of projections through the same plane. A computer program then processes the signal level data into a density map of the cross section termed a tomograph.

Figure 8 shows a tomograph of the interior of a southern pine log — no crosscut was made. Clearly visible are earlywood and latewood bands, pith, juvenile wood, pitch streaks, a knot located at the lower left periphery, and two areas of annual ring deviation near knots. A series of such tomographs would result in a three-dimensional image of the entire log.

It would not be necessary to display the visual image in the application proposed here. Rather, density data would be stored in numerical arrays and manipulated directly using pattern and texture recognition techniques. To simulate this process and illustrate the type of information that can be obtained from successive slices, the tomograph of Figure 8 was scanned and digitized using the previously described instrumentation. For this example, the log cross section and the knot (lower left of Fig. 8) was operator selected for analysis — a process simulating the proposed pattern recognition algorithm. Data from the analysis is given in Table 5.

The analysis shows the fast grown, noncircular stem in the 9-inch diameter class with a cross-sectional area of 62.9 square inches. Its center coordinates are $X=9.6$ and $Y=5.7$. Additionally, there is an oval knot of 1.6 square inches located at coordinates $X=6.9$ and $Y=8.1$.

Using information developed by the log defect detection algorithm, a third computer program determines the log positions needed to maximize grade or value yield. The program automatically positions and turns the log as needed, activates the log dogs and carriage stroke, and sets feed speeds.

If the proposed log breakdown system was used to cut hardwoods for furniture parts, most boards would still contain defects (i.e., knots, wane, stain, worm holes, checks) which must be removed if clear cuttings are required. Ongoing research at the Southern Forest Experiment Station is using optical scanning techniques to identify and locate surface defects in lumber as part of a laser cutting system to replace conventional processing methods in a furniture dimension rough mill. The envisioned system will use image-derived defect data to compute complex cutting patterns yielding the maximum number of clear pieces from variable sized boards. The entire process from defect scanning through laser cutting and sorting of pieces will be under computer control.