HARDWOOD LOG BREAKDOWN DECISION AUTOMATION

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ABSTRACT

This paper examines the use of internal log defect information, such as can be obtained from noninvasive defect detection imaging, e.g., computed tomography, magnetic resonance, etc., in the automation of log breakdown decisions for hardwood logs. A method was developed to extract the information and convert it into a form that can directly drive the saw equipment controllers to perform the log breakdown. This method illustrates the feasibility of hardwood log breakdown decision automation.

Keywords: Log breakdown, hardwood, decision automation, pattern-directed inferencing, wood engineering.

INTRODUCTION

Faced with competition from synthetic wood substitutes and imported wood products, the United States forest products industry must seek alternate methods of wood utilization as well as productivity improvement in current production operations. The research presented in this paper pertains specifically to hardwood log breakdown in the sawmill. Owing to the nature of the end utilization, the log breakdown practice for hardwoods differs from that for softwoods. In softwoods, the primary objective is to maximize lumber volume recovery, resulting in patterns, such as best opening face (BOF), which are founded on geometric considerations. Though some softwood log breakdown optimizers are value-driven, the value is derived more from lumber dimension than from face quality. In hardwoods, however, the objective is to minimize defects on the lumber faces, resulting in highly judgmental breakdown decisions performed by the sawyer in patterns such as grade sawing or around-sawing.

Thus, whereas the softwood log breakdown problem is generally geometric, the hardwood log breakdown problem is both geometric and defect-oriented. Over the years, the human sawyer has been calling saw placement decisions based on the limited information provided by the external view of the log shape, visible external defects, and whatever internal defects are eventually revealed on the cut log faces by the sawing pattern. Planning of how the hardwood log can be sawn to improve recovery of high-value lumber is hampered by the inability of the sawyer to foresee or "see" the internal defect distribution and orientation inside the log.

Recent work on the application of computed axial tomography and other means of noninvasive internal scanning of solids have opened up new avenues in the log breakdown planning problem (Donald et al. 1990; Wagner et al. 1989; Chang et al. 1989; Funt and Bryant 1987; Taylor et al. 1984). With new information now available related to the distribution and orientation of internal defects that can degrade the lumber value, questions arise on how this new information can be put appropriately to best advantage. Do we need to recognize each individual defect? How do we organize and process the internal defect information? How do we use it to determine sawing cuts? Will it really make a difference?

This paper presents a study conducted to answer some of the above questions, particularly how such new information can be best put to use. A method was developed to extract internal log defect information similar to what may be obtained from a noninvasive scanning, to characterize the information using computer aided techniques, and to convert it into a form that can directly drive the saw equipment controllers to perform the log breakdown. This method illustrates hardwood log breakdown decision automation.

A sawmill is envisioned where a log is scanned by an internal defect detection device before the log is sent to the saw headrig. By the time the log reaches the headrig, a breakdown plan on how to saw the log will have been generated by the computer to assist the sawyer, and downloaded to the saw numerical controller. Figure 1 illustrates the flow of both information and material. The research scope is indicated in the flowchart, with the preprocessed log and defect information as the input to the system, and the sawing instructions generated for the saw numerical controller as the output.

The objective of the research was to use the internal defect information, similar in type to information obtained from a noninvasive log scanner, to generate a specific breakdown plan for that log, and to implement this breakdown plan generation process automatically. Success in using noninvasive log scan information directly to drive saw controllers has not been reported previously. This research contributes to the ongoing effort in this area. It is worth noting that while on-line implementation is the ultimate goal, automated log breakdown decisions can be realized today with current equipment and processing speeds, albeit in an off-line mode.

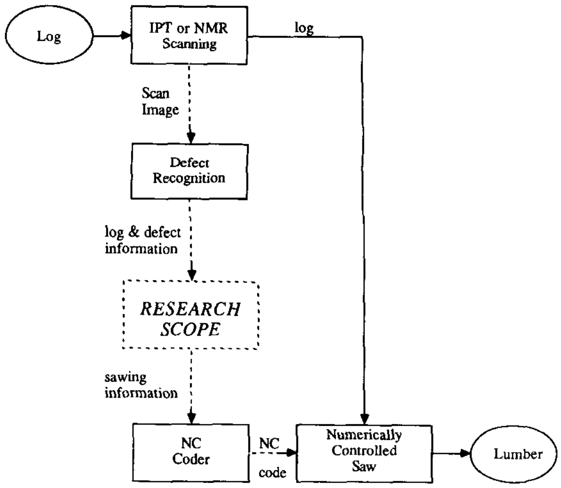


FIG. 1. Information and material flow.

RESEARCH APPROACH

A pattern-directed inference model and supporting analytical tools were developed to handle the automated breakdown plan generation.

To gain familiarity with the log breakdown process and to obtain data for modelling, sawmill visits were made in which six yellow poplar logs were sawn for grade. Figure 2 shows the type of data collected, which includes measurements of dimensions and external defect locations before sawing, photographs and videotapes of the breakdown process, and measurements of dimensions and internal defect locations after sawing. While originally different in form, these data were used to reconstruct the same type of three-dimensional solid log and defect information on computer that could be reconstructed from cross-sectional tomographic images.

Figure 3 summarizes the research approach in schematic form. The research was conducted in two phases. Phase 1, depicted on the right-hand side of Fig. 3, was a sawing analysis activity. An interactive graphic sawing simulator interfaced to a lumber grading program was developed (Occeña and Tanchoco 1988), and used to repeatedly saw sample logs under various breakdown patterns. The sawing simulator enabled three-dimensional graphic representation of solid logs, and simulated their breakdown using regularized constructive solid geometry (CSG) Boolean operations. The sample yellow poplar logs were reconstructed using the simulator and were used in the sawing pattern analysis.

The knowledge gained from the sawing simulation experiments was then formalized in a knowledge base that formed the basis for Phase 2. Phase 2, shown on the left-hand side of Fig.

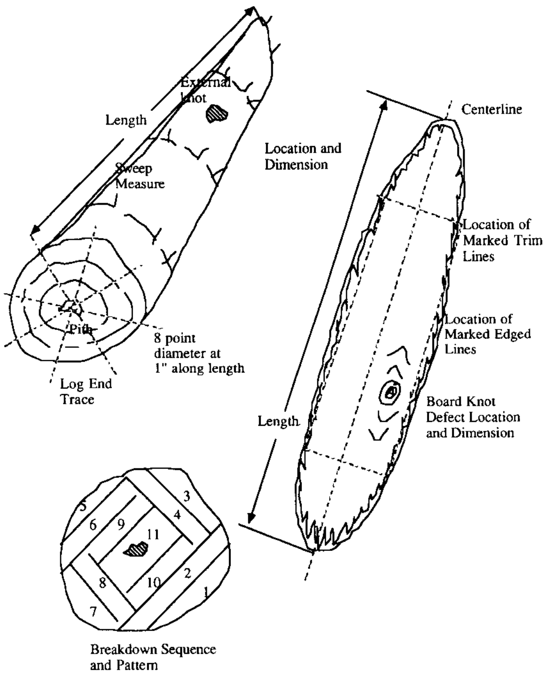


FIG. 2. Sample data collected from sawmill site visits.

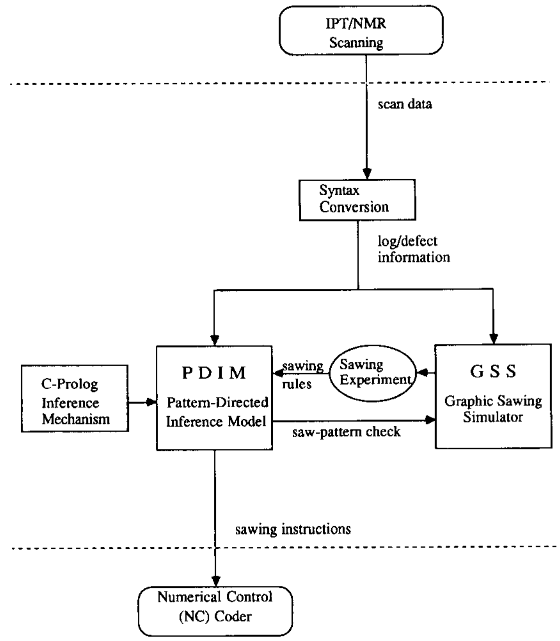


FIG. 3. Research approach flowchart.

3, involved the development of a pattern-directed inference model that could generate a set of breakdown instructions from the log and defect information, using the breakdown rules in the knowledge base and a logic-based inference mechanism. The C-Prolog declarative programming language used for modelling came with a built-in depth-first back-tracking mechanism, and a predicate logic representation format. The former was coupled with rule ordering to provide a more powerful best-first search strategy. The interactive sawing simulator was used to nondestructively verify the computer-generated breakdown plans.

DESCRIPTION OF MODEL DEVELOPMENT

Sawing analysis via graphic simulation

A graphic sawing simulator named GSS (Graphic Sawing Simulator) was developed as a supporting analytical tool for studying the hardwood log breakdown process. The GSS was based on the solid modelling concept of boundary representation, which represents a solid in a hierarchical relationship composed of component faces, edges, and vertices in three-dimensional space. A polyhedral solid modeller (Mashburn 1987) that simplifies solid representation through the use of polygonal patches was accessed in batch mode to handle the sawing effect via regularized constructive solid geometry Boolean operations. A flitch can be "sawed" off a log, for example, by an intersection Boolean operation between a log representation and a saw representation. The remaining log can be obtained as the result of a difference Boolean operation between the same set of solids. The resulting flitches were then edged and trimmed automatically, and graded by a computer grading program (Huang and Sparrow 1989) to arrive at a value yield for the log.

The core of the GSS was a FORTRAN program that read in log and defect information from data files and rendered the log and defect images graphically using a device-independent graphics package (DI-3000 1984). The program then makes program calls to the polyhedral solid modeller to perform interactive sawing simulation, and to the grading program to evaluate the resulting lumber. The interactive sawing was implemented on a Tektronix 4105 raster graphics terminal running under Berkeley Unix on a VAX 11/780. Development of the GSS was reported by Occeña and Tanchoco (1988).

Log and defect reconstructions and decompositions

Following the polyhedral format of the solid modeller, the sample data had to be converted to boundary representation format. The representation was performed in three stages: first, the raw data were preprocessed to relate to the source. Second, polygonal loops were formed to define each face of the flitch, slab, or defect; and where needed, multiple triangularizations were done. Third, the polygons were arranged in polygon file standard. The log and internal defects were built up from the flitch data to enable reconstruction of the location and orientation of internal defects. This activity benefitted greatly from the Boolean union operation capability of the GSS.

Simulated sawing experiments were used to test several traditional sawing patterns, e.g., live-sawing, cant-sawing, around-sawing, as well as nontraditional sawing patterns, i.e., sawing decisions dictated by the log and internal defect appearance.

Pattern directed sawing policy

From the simulated sawing analysis, it was found that when internal defects were aggregated, i.e., viewed as a group as a sawyer would from a distance rather than as individual defects, they formed specific configurations with distinctive axes. By bounding or splitting these configuration axes, the defects can be contained in a few flitches or confined to the edges for easy removal in finishing operations, respectively. Another consideration in the analysis was the importance of obtaining wide lumber as a secondary goal. Four configuration types or patterns for classification were identified—namely, Clear Log, Single Dominant Axis, Multiple Dominant Axes, and No Dominant Axis.

The Single Dominant Axis (where defects formed only one distinct axis) and the Clear Log (where defects were insignificant and the log was essentially defect-free) configurations were the simplest cases, where the breakdown plan was to live-saw, parallel to the defect axis in the former case, and parallel to the widest side in the latter case. The resulting patterns were effective in containing the defects in the fewest flitches. For the Multiple Dominant Axes (where defects formed several distinct axes) configuration, recursive decomposition of the log into log sections by sawing parallel to major axes eventually resulted in log sections that were of the simple cases. Thus the sawing policy can be considered as a decomposition procedure that recursively reduces a complex case to a set of well-defined simple cases. The No Dominant Axis (where defects were confined to the heart of the log and did not exhibit distinct axes) configuration was treated as a special case that required around-sawing.

The aggregate results of the sawing experiments are summarized in Table 1, showing the pattern-directed procedure in the last column performing well in the higher grades. This outcome was consistent with the objective of containing defects in the fewest flitches. Though no statistical analyses were done because of the small sample size, the pattern-directed procedure shows up as a viable approach for automated hardwood log breakdown planning.

The automated model

The automated model, named PDIM (Pattern Directed Inference Model), was implemented as a knowledge-based system because of the presence of multiple conditions, which when combined together produced a specific action. The knowledge-based structure also provided ease of knowledge manipulation, as well as the modularity of a detached knowledge base. Facts and rules were asserted and retracted only as needed. C-Prolog was a suitable representation medium because of its declarative syntax and built-in features of backtracking, resolution-proving, and pattern-matching that enabled inferencing.

The log and defect information was first converted into Prolog fact clauses, then subjected to defect configuration extraction and characterization using rule clauses resident in the knowledge base (Occeña and Tanchoco 1989). The two latter processes constituted the automated recognition capability of the system, which carries out the visual recognition step normally performed by the human sawyer. This capability was considered superior to a graphic imaging approach because of the elimination of the time-consuming image processing and rendering steps. This capability parallels efforts in the integration of computer-aided design and manufacturing in metal processing (Henderson and Anderson 1987; Choi et al. 1984). Once the defect configuration had been extracted and characterized, it was then processed automatically by rule clauses based on the pattern-directed sawing approach described earlier. Finally, a set of log positioning and sawing instructions was generated, which could be converted to numerical code to drive the saw controller.

Automated defect configuration extraction

The defect configuration was extracted automatically in five steps: log boundary extraction, initial defect filtering, density measurement, density filtering, and defect hull extraction. In the first step, the log boundary was extracted to define the computational workspace. The same log boundary was used as a reference in the second step for the initial filtering of defects. The filtering was done to screen out defects near the log ends and log surface. The premise was that these defects would eventually be removed by subsequent operations such as edging and trimming, and need not be carried over in the analysis.

The three-dimensional defect data were then mapped onto two-dimensional space in the third step by summing up the Δzs (longitudinal length) for each (x, y) pixel. This mapping was done to avail of well-defined characteristics of two-dimensional graphs. The resulting two-dimensional values were called density measures because they represented the intensity of the defects along the longitudinal length of the log. Density measures less than 1¼ inches were discarded in the fourth step, on the premise that they will not affect the grading because the minimum degrading defect size in the standard NHLA grading rules is 1¼ inches.

The remaining density measures represented degrading defects. The defect configuration was extracted in the final step using a defect hull procedure that scanned the extreme y points along the x-axis and the extreme x points along the y-axis, and concatenated the resulting lists into an ordered list. The ordered list defined a defect hull. The hull was not convex, yet that was precisely desirable because it allowed the accumulation of defects to appear in the form of axes.

Automated defect hull characterization

After the hull was extracted, it then had to be characterized to determine the appropriate treatment. The characterization was done using the inflection point/axes relation procedure. The procedure called first for the identification of hull points that were inflection or transition points in the directed hull. An inflection point was considered a potential defect axis vertex if it satisfied two necessary conditions: (1) the inflection point was convex in a counterclockwise sweep of the hull, and (2) the inflection point was dominant relative to neighboring inflection points.

The convexity test was performed using the right-hand rule (Preparata and Shamos 1985). The dominance test consisted of two phases. Phase 1 established the edge relations. Combinations of v and c denoted the position of an edge in the directed transition between bounding inflection points, where v stands for concave and c stands for convex. For example, vc defined an edge bounded by the transition to a concave point from a convex point in the counterclockwise direction. Phase 2 examined the characteristics of the v and c combinations to ensure that the height of the inflection point was greater than its base width. For example, cc $\rightarrow$ vc or cv $\rightarrow$ vc combinations denoted a

TABLE 1. *Summary of simulated sawing results. Numbers in bold denote maximum value in set.*

Grade	Aggregate results for six logs. Units are in surface measure and (number of boards)				
	Sawing pattern				
	Original*	Live	Cant	Around*	Pattern
FAS	88 (12)	31 (4)	31 (4)	91 (12)	**100 (13)**
Saps	7 (1)	66 (9)	42 (6)	7 (1)	**76 (13)**
Selects	46 (6)	**136 (15)**	56 (8)	44 (6)	97 (14)
1C	214 (32)	**250** (31)	242 (**40**)	241 (31)	167 (25)
2AC	149 (20)	199 (24)	207 (28)	139 (18)	**217 (31)**
2BC	71 (10)	22 (4)	**77 (20)**	75 (11)	34 (4)
3AC	2 (1)	—	—	4 (1)	—
Total	577 (82)	**704** (87)	655 (**106**)	601 (80)	691 (100)

* Cant not resawed.

potential axis, for which the bisector length and base width line ratio was checked. A ratio $\gg 1$ indicated an axis vertex. The internal defect configuration extraction and characterization were reported by Occeña and Tanchoco (1989).

Log breakdown decision automation

The pattern-directed sawing policy was formalized as a set of If-Then production rules. These production rules covered all four cases of defect configurations. In Prolog format, the four cases are summarized by the following clauses.

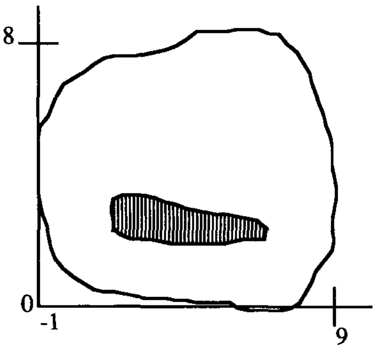
```
first_level_rules(Label) :-
    logdef_status(Label,no_defect),
    worklog(Label,_,Status),
    commence_cut(Label,Status).

first_level_rules(Label) :-
    logdef_status(Label,defect_but_no_axis),
    elsd_compute(Label,Opening_face,Procedure),
    cant_or_saw(Label,Opening_face,Procedure).

first_level_rules(Label) :-
    logdef_status(Label,single_axis),
    worklog(Label,_,Status),
    single_axis(Label,Status).

first_level_status(Label) :-
    logdef_status(Label,multiple_axes),
    worklog(Label,_,Status),
    multiple_axes(Label,Status).
```

The sub-clauses commence_cut, cant_or_saw, single_axis, and multiple_axes are program calls to other clauses that perform the appropriate processing corresponding to the type of defect configuration detected. The breakdown decision module operates in a recursive mode. The input consists of the log boundary and defect configuration descriptions. The concept is to reduce the log or log section to either a single dominant axis case or a no-defect case, which are well-defined. Thus the outcome of any pass through the rules is always to make a cut, unless the log section is a final dogboard.

A cut made will result in two log sections. The log sections will either be completely sawn or recursed to the top of the rule stack. If there is a call for recursion, the log boundary is redefined to accommodate for the newly sawn face, and a list of major defect axes in the newly bounded log section is generated. A decision to split through a major axis removes that axis from the list of active defect axes because it puts the defects in positions where they are likely to be edged, trimmed, planed, or simply cut off in the breakdown process.

RESULTS

The output of the hardwood log breakdown decision automation model consists of a list of sawing instructions that are in a format amenable to transformation into numerical control code for controlling the saw. The instructions were generated simultaneously as the breakdown pattern was being developed. For example, every time a new axis was considered, a log rotation was implied. The set of instruc-



SAWING INSTRUCTIONS

rotate log_boundary1 75.1276 degrees clockwise
index log_boundary1 2 inches forward
Saw ... for resaw1
for stability , position cut face down or towards carriage
in current position log_boundary2 is 2 inches wide
and 9 inches high
index log_boundary2 towards saw 0.75 inches
saw
for stability , position cut face down or towards carriage
in current position log_boundary3 is 6 inches wide
and 9 inches high
index log_boundary3 towards saw 1 inches
saw
index log_boundary3 towards saw 1.25 inches
saw
index log_boundary3 towards saw 1.25 inches
saw
index log_boundary3 towards saw 1.25 inches
saw

yes
prelims consulted 2972 bytes 32.2167 sec.
startup consulted 87988 bytes 53.9833 sec.

FIG. 4. Sample generated saw instructions for a small log with a single dominant axis. Small-end view shown for log boundary and defect configuration.

tions generated was sufficient to determine a breakdown for the given log. It must be noted, though, that because the model proceeds in a decomposition process, i.e., from a whole log to log sections, then from log sections to flitches, the instructions proceed in the same way. It is possible, therefore, after the log sections with their individual breakdown patterns are put together to form the whole log, that some of the sawlines belonging to different log sections will be collinear. This case implies that the actual execution of the breakdown pattern may be accomplished in fewer passes, skipping the log section phase. Resolution of this issue is an ongoing research extension. Figure 4 shows a sample two-dimensional log boundary and defect configuration, and the corresponding sawing instructions generated by the model.

CONCLUSIONS

The paper presents the results of an exploratory study to determine automatically a hardwood log breakdown pattern from internal log defect information. The breakdown pattern generated was based on the defect configuration detected inside the log. This development is relevant to the concurrent work being done in the noninvasive imaging of hardwood logs. The approach used in the study was described, including the modelling of logs and defects using polyhedral boundary representation, a graphic sawing simulator, a pattern-directed sawing policy predicated on making cuts parallel to a dominant defect axis, its implementation as a recursive decomposition procedure, a procedure for extracting and characterizing defect configurations as defect hulls, and a pattern-directed inference model for hardwood log breakdown decision automation.

The outcome of this study demonstrated the feasibility of using internal log defect information, similar to that obtained from noninvasive scanning, to generate hardwood log sawing instructions automatically. Further work and testing needs to be done to evaluate the effectiveness of the model in extracting higher value yields. The log breakdown pattern generated by the model was not yet optimized because optimization was only secondary to the primary goal in this study of establishing the feasibility of automating the generation of hardwood log breakdown decisions from internal log defect information. The study, however, provides a working alternative for using noninvasive scan type of information. Optimization of value yield is certainly a logical next step. The model is in its infancy stages. More work needs to be done if the intent is to use it to improve hardwood sawmill productivity. Ongoing research to extend the model includes interfacing with noninvasive scanner data output, optimization of value yield, incorporation of edging decisions, and porting of the modules to microcomputer platforms.

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