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True-shape and defects data from mountain pine beetle-affected stems

Jan Brdicko

Mountain Pine Beetle Initiative
Working Paper 2007-04

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Mountain Pine Beetle Initiative Project # 8.34

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Abstract

A sample of 233 mountain pine beetle-affected logs was collected from the log yard of Tolko Industries Ltd., sawmill in Quesnel, BC. The log sample was selected to represent the range of deterioration resulting from green, red and early grey stages of beetle attack. All logs in the sample had partially or fully developed blue stain in the sapwood. Some of the logs showed very minor checking, whereas the remainder had single and multiple checks of variable depth, some extending to the pith, and over a large part of log length. In addition, the wood grain in many of these logs was spiral, further compounding the beetle-induced damage. The majority of the logs selected were “cut-to-length”. A few full-length stems were included and bucked into 10-foot logs that were individually identified so that images of the original stems, complete with defects, could be reassembled.

Forintek’s blue-stain and check-detection system was installed on the large-log processing line of Tolko’s Quesnel sawmill, and interfaced with the mill’s existing true shape-scanning system. The two systems were used together to collect true shape and mountain pine beetle-induced defect data from the sample logs. The true shape and beetle defect data were transposed into a format suitable for Optitek®, Forintek’s sawmill modelling program. In addition, measurements of beetle-induced defects were collected for five logs bucked from one beetle-killed tree using Forintek’s CT scanner and Forintek’s laser scanning and blue-stain and check-defect detection systems. These two sets of measurements were used to compare, and highlight, the relative capabilities of these two different technologies.

Résumé

On a prélevé un échantillon de 233 grumes attaquées par le dendroctone du pin ponderosa dans le parc à grumes de Tolko Industries Ltd., une scierie située à Quesnel, en Colombie-Britannique. L’échantillon de grumes a été choisi de façon

à représenter les différents degrés de détérioration causée par les stades vert et rouge, ainsi que par le début du stade gris de l'infestation par le dendroctone. Toutes les grumes de l'échantillon comportaient sur l'aubier des taches bleues partiellement ou complètement développées. Certaines grumes ne présentaient que très peu de gerces, alors que le reste présentait une ou plusieurs gerces plus ou moins profondes, certaines s'étendant jusqu'à la moelle et sur presque toute la longueur de la grume. En outre, le fil de la plupart de ces grumes était en forme de spirale, aggravant encore les dégâts infligés par le dendroctone. La majorité de ces grumes ont été « mises à longueur ». Quelques troncs entiers ont été inclus et tronçonnés en grumes de 10 pieds (3 m) de long qui ont été identifiées pour pouvoir reconstituer les photographies des troncs complets avec les défauts.

Le système de détection des gerces et des taches bleues de Forintek a été installé sur la tête d'ébranchage-tronçonnage des grumes larges de la scierie de Tolko, à Quesnel, et utilisé conjointement au système de scanneur de forme réelle de la scierie. Les deux systèmes ont été utilisés ensemble pour collecter des données sur la forme réelle et les défauts infligés par le dendoctrone du pin aux échantillons de grumes. Ces données ont été transposées dans un format adapté au programme de modélisation de la scierie de Forintek, Optitek®. En outre, on a mesuré les défauts infligés par le dendroctone à cinq grumes prélevées sur un arbre tué par le dendroctone au moyen du CT-scanneur et des systèmes de balayage laser et de détection des défauts et des taches bleues de Forintek. On a utilisé ces deux ensembles de mesures pour comparer et mettre en évidence les capacités relatives de ces deux technologies. différentes.

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1 Introduction

Logs from trees that have been attacked by the mountain pine beetle develop two main defects that impact lumber production: blue stain and checks. The blue stain develops within months of the beetle attack and, as the tree dries, the degree of checking increases with time to the point at which, in "grey stage" trees, the checking is fully developed. When sawmills process logs from mountain pine beetle-attacked trees, value and volume recovery decrease relative to logs from healthy trees. The extent of the decrease depends mainly on the severity of checking.

It may be possible to reduce the negative impact of blue stain and check defects through the use of innovative or emerging technologies intended to mitigate value and volume losses associated with producing lumber from mountain pine beetle-attacked trees. Such technologies include scanners that can detect beetle-induced defects such as stain and checks, and optimisers that will minimize the impact of these defects by generating breakdown solutions based on consideration of log positions and rotation angles.

As a step towards addressing the problems associated with processing beetle-attacked timber, and in order to determine the potential benefits of emerging technologies, the purpose of this project was to collect data quantifying checks and blue stain, as well as stem and log shape. These data are required as "input" for the sawmill modelling[1] program Optitek® which is used to estimate the impact of beetle-induced defect on sawmill performance and to facilitate decision making focused on optimizing value recovery from the post-beetle infestation log resource.

2 Objectives

1. To collect data detailing log shape, checks and blue stain characteristics from a sample of mountain pine beetle-affected trees and to process the data in such a way as to render it suitable for use in a sawmill simulation program called Optitek®.
2. To describe the data collection method and results.

3 Materials and Methods

3.1 Log selection and preparation

A sample of 233 mountain pine beetle-affected lodgepole pine logs was selected in the log yard of Tolko Industries Ltd. sawmill in Quesnel, BC. Based on information provided by Tolko, the logs came from cut block 03; cutting permit

[1] This modelling work is part of the Canadian Forest Service Mountain Pine Beetle Initiative Project #8.07 *"Quantifying Lumber Value Recovery from Beetle-killed Trees"*.

092; and Forest Licence FLA20010. The sample includes, in our judgement,[2] all "levels" of blue stain and checking damage associated with the green, red and (early) grey stages of deterioration. Most of the log yard inventory at the time of sample selection had been harvested and transported in the form of cut-to-length logs. Consequently, the majority of the 233 logs evaluated as part of this work were not sourced to a "parent" tree. Also, logs with a top-diameter less than 15 cm are under-represented in the sample because only the "large-log line" of the collaborating sawmill could be used for this study.

The selected stems and the cut-to-length logs, with the bark on, were laid out on skids in the log yard. Starting from the butt end, the stems were manually bucked into logs approximately 10-feet in length. The final log, the top log, was typically left longer by several feet. The cut-to-length logs were not bucked, but where required, thin slices were bucked from the log ends to provide the clean, smooth faces required by the machine vision system. Tags identifying each log were stapled to the log faces where they would not obscure the blue stained areas, the checks or the pith. The logs were then debarked and loaded onto the mill's large log in-feed deck.

3.2 Data Collection

Forintek's blue stain and check detection system (described in Appendix 3) was installed in the collaborating mill's large-log processing line, just downstream from the mill's existing true shape scanning system.[3] The sample logs were conveyed, one at a time, through the mill's true shape log scanning system and the blue stain and check detection system. The defect detection system was used to collect digital images of the sides and end surfaces of each log, while the scanning system was used to collect true shape data. At Forintek's laboratory in Vancouver, the digital image data were processed to delineate the blue stain and check defects, and the data describing these defects were subsequently "merged" with the true shape data. The true shape and mountain pine beetle-caused defect data were then transposed into a format suitable for Optitek®, Forintek's sawmill modelling program.

The data formatting and log image processing are discussed in greater detail in Appendix 2 and Appendix 3 respectively.

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[2] It must be noted that the sample does not provide a statistical representation of the actual extent of blue stain and check damage present in the green, red and grey stages associated with MPB-attacked trees. Neither is the sample representative of the full extent of damage that has occurred within any specific region, forest-license or cut-block. Because they were not present in the mill log yard, logs with the most severe beetle-induced damage that one can expect to find associated with the later grey stages of MPB attack were not included in the sample.

[3] Alternative means of collecting blue stain and check data were considered including manual measurement on location or transporting the logs to Forintek to be scanned. Installing the Forintek blue stain and check detection system at the sawmill was determined to be the most effective and least costly method.

4 Results and Discussion

Dimensional data of the 233 sample logs, including log number, averages of diameter, sweep, taper, and length, are provided in Table 3 in Appendix 4. Table 3 also shows the basic statistics for each of the types of dimensional data. Figure 16 in Appendix 4 shows the small end diameter distribution of the sample of logs. Table 1 below summarizes defect data for one log.

In all sample logs, wood with blue stain was delineated very clearly from clear wood, with the blue stain coinciding with the sapwood–heartwood boundary. The image processing software and/or the human “editors” were able to reliably detect checks which were wider than approximately 1 mm on the log end faces, and 3 mm on the log side surfaces. The main cause for these detection limits was that the logs were generally under-debarked and the ends and sides were marred by either the debarker tools or the press rolls.

Logs with severe checking, which are more likely to occur in trees in the late grey stage of mountain pine beetle attack, were probably under-represented in the sample of the logs that were collected. However, the preliminary results from Optitek® show that the blue stain and check defects in many logs in the sample resulted in a 50% or greater decrease in value recovery.[4] Hence the severity of beetle-caused defects of logs included in the sample is sufficient to meet the (practical) objectives of sawing optimization.

[4] See the parallel Canadian Forest Service Mountain Pine Beetle Initiative Project #8.07, working paper 2006-09.

Table 1. Sample log defect summary for one log

LOG SECTION:

Log ID	Length (in)	Large End Diameter (in)	Small End Diameter (in)	Check Severity	Check Spirality	Number of Checks	Number of Stains
L1	240	13.555	11.33	0.158	1.5	3	1

CHECK SECTION

Log ID	Number of Checks	Check ID	Length (%log)	Start Position (%log)	Average Width (mm)	Average Depth (%radius)	Average Depth (in)	Angle (deg,CW)	Spirality (deg/m)
L1	3	1	22.49	40.02	0.41	66.76	4.201	129.1	7.4
		2	29.99	70.01	0.61	39.07	2.278	152.2	7.2
		3	25.03	0	0.41	77.09	5.117	18.8	3.1

STAIN SECTION:

Log ID	Number of Stains	Stain ID	Length (%log)	Start (%log)	Angle Width (deg)	Average Depth (% radius)	Average Depth (in)	Angle (deg, CW)
L1	1	5	100	0	360	17.99	1.13	0

The extent of damage in trees attacked by mountain pine beetle tends to be described in terms of time-based “colour” stages, namely green, red or grey. Generally, the “severity” of checking of beetle-killed trees increases with each stage, but the increase is not linear and there is considerable overlap, particularly between the red and grey stages. The extent of damage is, in fact, unique to each tree and varies both between and within a particular harvested area. Segregation of fibre into time or “colour” based stages of beetle attack may be of some use in describing the condition of standing trees; however, it is of limited use once the trees are harvested, delimbed, delivered to sawmill log yards and mixed with other delimbed trees. At that point it is very difficult to visually inspect a log or stem and identify its “colour” stage.

Because the logs were selected in a mill log yard, the sample logs could not be unambiguously identified as being from either the green, red and grey stages of mountain pine beetle attack. Given the absence of an established, systematic method for quantifying the “severity” of checking of logs, it was necessary to formulate a simple “severity of checking factor”, as described in Appendix 1. This factor was used to sort the sample of 233 logs in ascending order based on the “severity” of checking, as shown in Figure 1. Table 2 below provides the information about the extent of checking in the three logs pointed at in Figure 1. In this example, all three logs have only one check, log L214 has the deepest check, and log L242 has the shallowest check.

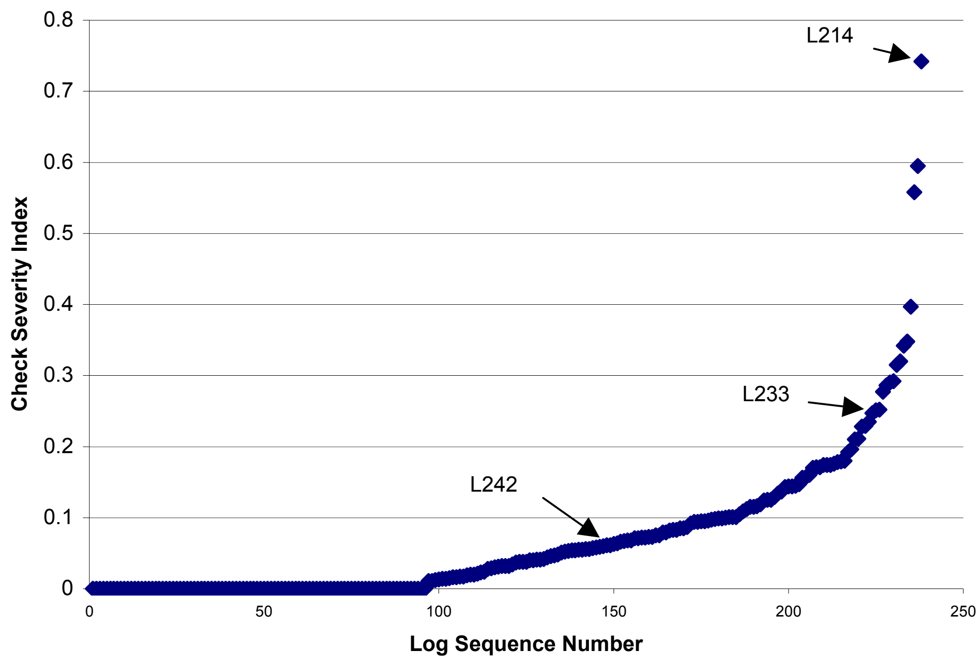

Figure 1. Severity of checking for all sampled logs

Table 2. Data extract from log summary

LOG SECTION:

Log ID	Length (in)	Large End Diameter (in)	Small End Diameter (in)	Check Severity	Check Spirality	Number of Checks
L242	247	14.385	11.44	0.048	1.8	1
L233	188	10.055	9.335	0.15	2.1	1
L214	159	8.46	7.15	0.74	3.4	1

CHECK SECTION:

Log ID	Length (%log)	Start (%log)	Average Width (mm)	Average Depth (%radius)	Average Depth (in)
L242	7.28	36.39	0.25	62.39	4.077
L233	19.06	28.59	0.21	77.98	3.799
L214	100	0	0.5	62.93	2.429

5 Conclusions

This project has achieved its main objective – the collection of true shape, blue stain and check data, on a log-by-log basis, for the creation of a sample of 233 mountain pine beetle-killed logs. This sample will serve as valid input data for the Canadian Forest Service Mountain Pine Beetle Initiative Project #8.07 *"Quantifying Lumber Value Recovery from Beetle-killed Trees"*., working paper 2006-09.

The project has also provided better appreciation of the problems and potential benefits of using systems similar to Forintek's blue stain and check detection system aimed at improving lumber recovery from beetle-killed trees.

6 Recommendations

The blue stain and check detection system, and the image processing methodology used in this work are shown to be a robust and efficient means of providing a large quantity of beetle-caused defect data. There are opportunities to use this technology for further, more comprehensive analysis of the beetle-affected resource.

The defect detection system and the image processing methodology should be used to collect data for a larger sample of logs showing the most severe checking. This will facilitate a greater understanding of the value and volume losses associated with processing logs in the late grey stage of mountain pine beetle attack. Such an understanding is required as the industry continues to process logs with more and more beetle-induced damage.

A practical "severity of checking" index should be developed using Optitek®, and data collected by the defect detection system. This index should correlate with lumber value recovery, and be easily calculated or estimated for a specific tree or log. The feasibility of using the index to evaluate trees or logs either with or without bark during harvesting and/or processing operations should be investigated.

7 Acknowledgements

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Our thanks go to Quest Wood Products, a division of Tolko Industries Ltd., for providing the sample logs and for making their log yard and sawmill available for data collection. The team at Quest Wood graciously shared their knowledge and experience relating to the processing of beetle-attacked wood.

Appendix 1: Checking Severity and Checking Spirality Indices

Checking Severity Index

Checking is unique to each tree, hence careful sampling techniques are required to describe the "severity of checking" of a log. Due to the absence of an accepted definition of "severity of checking", in this project the following definition has been derived:

Let S be the Checking Severity for any log, and let S have range [0 <= S <= 1.0].

Let L = log length,

n = number of checks in the log,

Li = length of check ci

Di = depth of check ci

Ri = radius of the log

Consider the ratio of (Di / Ri) at a particular point along some check ci.

Define check depth weighting factors di to be the maximum value of all of the (Di / Ri) measured along the length of check ci

di = maximum (Di / Ri)

Similarly, let check length weighting factors wi for ci be given by:

wi = Li / L

The check severity si can be formulated as di • wi to represent a normalized area.

Then log checking severity S is defined as:

$$S = (1/n) \Sigma \mathbf{s_i}$$

The behaviour of S for a log with one check c1:

1) If L1 -> L, then S -> D1 / R1, where [0 <= S <= 1.0]

2) If L1 -> 0, then S -> 0

3) If D1 -> 0, then S -> 0

4) If D1 -> R1, then S -> L1/L

Example: The severity si of the ith check in a log. Consider a check of half the log length of 16 feet, of 60% of full depth of 10 inches (20 inch log diameter), as shown in the figure below. The severity of the check would be si = di • wi = (6/10) • (8/16) = 0.6 • 0.5 = 0.3

A full-depth, full-length check (not shown) would give $\mathbf{s_i}$ = (10/10) • (16/16) = 1.0

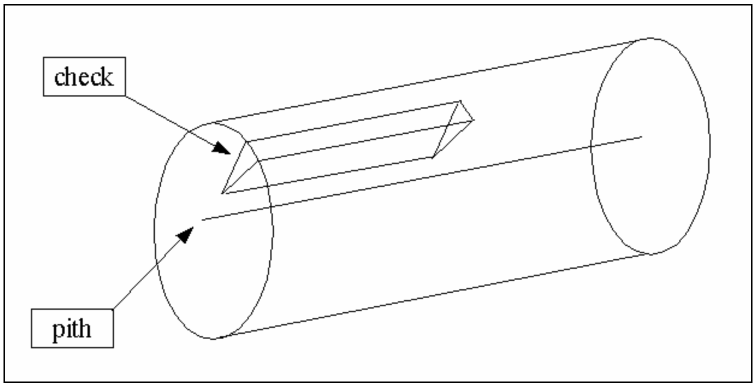

Figure 2. A sample log with one check

Checking Spirality Index

Spirality is the change in the angular position of a check along its length, and has units of degrees per meter (deg/m) in this report.

In order to provide a simple measure of overall log spirality (Sp) in a given log with some number of checks, the following definition is used in this report.

Let L = log length,

Li = length of check c_i

w_i is the ratio of check length to log length (L_i / L) for check c_i

sp_i is the spirality of check c_i, in degrees/meter units, always positive, and

n = the number of checks in the log.

Then Spirality (Sp) for a log is given by:

$$Sp = (1/n)\ \Sigma(w_i \bullet sp_i)$$

where Sp has range [0 <= Sp < 360] degrees.

Notes:

Adhering to the Optitek® convention, angles are referenced to the negative x-axis, and increasing angular values move in a clockwise direction. All angles θ fall in the range [0 <= θ < 360.0] degrees.

Note that the checks generally follow the fibre direction along the log length, and if the fibre is spiral, the check will also likely be spiral. However, the fibre spiral orientation is a characteristic of the tree fibre structure, which is then inherited by all the checks in the log.

Appendix 2: Transforming blue stain and check data into Optitek® format

Formatting of blue stain and check defects and the log shape data for Optitek® use

After the digital pictures for all logs were inspected, edited, and "mapped" onto the true shape points of these logs, it was necessary to "convert" these data into the format suitable for the Optitek® sawmill simulation study. This data "conversion" included the following steps.

The digitized check and stain features for each log, along with the corresponding scanned log images, were processed by Forintek's custom Log Imaging software. The Log Imaging software "painted" the check and stain features onto the surface of each log, and then propagated the surface features into the interior of the logs, producing a collection of Optitek®-compatible logs containing check and stain defects.

The propagation of surface features into the interior of logs involved a set of rules and conventions because the details of the interior structures of check and stain remain uncertain in their detail. In addition, the check and stain digitization process actually introduced additional check and stain structural uncertainties (this is our first use of the digitization software). The following rules and conventions were used to propagate surface checks and stains into the interior of logs:

Stain:

1. The digitized stain points define the inner surface of the stain body. Stain depth is calculated as the average depth/radius ratio of all the digitized stain points on a log face. Stain depth is measured from the log surface.
2. When stain is present on one log face, but not the other, then stain is propagated along half the log length (stain is not visible on the (side) surface of the log). The depth/radius ratio of the stain decreases linearly from the log face to half the original value at the log midpoint.
3. When stain is present on both faces of a log, then the stain depth/radius ratio varies linearly between the log faces.
4. As a first approximation, to avoid excessive complexity, if there is any stain in the sapwood of a log face, then stain is assumed to be present in all of the sapwood on the face. This assumption is somewhat supported by the high speed of stain propagation in sapwood.
5. For stain insertion, the pith point is the reference for the calculation of log radius and stain depth.

Checks:

1. When a check does not appear on either log face, but appears only on the log (side) surface, then the check width and log diameter are used to

calculate the check depth ratio. A regression equation derived from a sample of checked logs is used to perform the depth calculation. (We call checks digitized on a log face “face checks”, and checks digitized on the log surface (or side) “side checks”.)

2. When a check appears on one log face, this also defines its actual depth. The actual check depth is used to calibrate the regression equation to the check. The calibrated regression equation is used to calculate the check depth for the interior length of the check.
3. When a check appears on both log faces, again the actual check depths at the log faces are used to calibrate the regression equation at each face. The calibration varies linearly along the check between the log faces.
4. Since side checks are also digitized, checks acquire a spirality attribute (degrees/meter). In other words, the angular position of the check may vary along the log axis.
5. To model checks in a simple manner, it was assumed that all checks “point” toward the pith.
6. When digitizing face checks and side checks, we discovered that it is extremely difficult to estimate check width. The low resolution of the photos prevented the possibility of zooming in for a better look. Additionally, we discovered that check width is a function of moisture content, and therefore cannot be a reliable parameter for calculating check depth in this project.

Appendix 3: Blue Stain and Check Detection System

Blue Stain and Check Detection System was constructed by configuring Forintek pre-existing machine vision system hardware and software to capture digital images of the sides and ends of mountain pine beetle-affected logs travelling along a conveyor. The checks and blue stain defects, once identified in these captured images, are mapped onto the true shape images of the logs.

Detailed System Description

Six high speed digital cameras are used to capture the log images. They connect to a PC using an IEEE-1394 interface. Four of the cameras are located radially from the log centre and capture a series of images along the length of the log side as it travels along the conveyor. These images are used to detect checks along the length of the log. Two additional cameras aimed parallel to the log conveyor capture images of the log's two ends, and are used to detect end checks and blue stain there.

A log surface requires bright illumination for a high quality image to be captured by the camera. In addition, the direction of the light is important as the checks and blue stain defects are more easily identified when illuminated in a dark field. For this reason, specific strobed light emitting diode (LED) modules were optimally positioned, and used in conjunction with each of the six cameras to capture best possible images. Coaxial cable connects the cameras to the lights through special logic circuitry to automatically turn on the appropriate set of lights whenever a given camera is integrating light.

A photo-detector is placed upstream of the system to detect log arrival, and a rotary encoder measures the travel of the conveyor. The outputs of both devices are continually sent to the PC using an RS232 connection.

A bolted frame holds the cameras and lights in their proper positions around the conveyor. The light/camera system that takes pictures of log sides is shown in Figure 3. The system for taking pictures of log ends is shown in Figure 4, shown as it is taking an image of the leading face of a log. Imaging of the trailing edge occurs once the log has travelled past the frame shown in Figure 4.

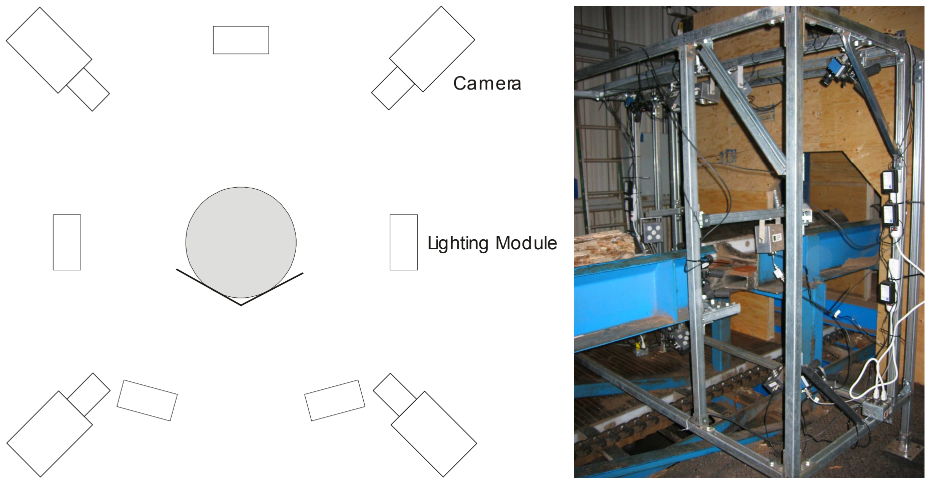

Figure 3. Camera and side light positioning and mounting frame

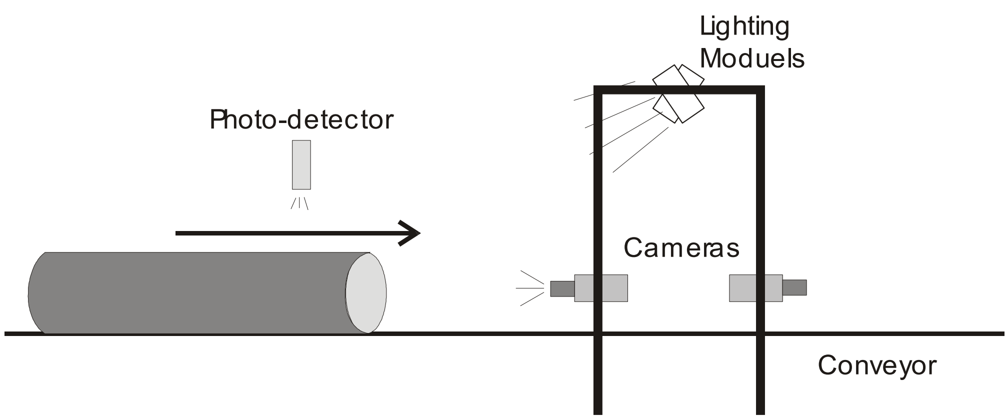

Figure 4. Imaging a log's leading face

The Blue Stain and Check Detection System was installed on the line directly after the scanner heads. The logs would come in from the outside and would trigger the photocell then pass through the scanner assembly. Then the given log would pass through the blue stain check detection system. Sixteen-inch long slots were cut in the log conveyor guards and support structure in order to provide a clear view for all cameras. The bolted frame was constructed around the slots in the conveyor guards. The frame was then levelled and bolted to the ground. Finally, all the necessary electronic components were attached to the frame and calibrated. The calibration procedure is described later in this appendix.

The selected and tagged logs were debarked and loaded onto the mill in-feed log decks and then put onto a large log conveyor for the passage through Forintek's check and stain detection system and the log true shape scanning system. For each of these logs, the log shape data that were collected from the mill true shape laser scanning system, and the digital pictures including check and stain data from Forintek's system, were correlated and stored into a database. Images stored for each log consisted of the top and bottom faces and four-side full log length images, each representing 45 degree separation along the log axis.

The side cameras and lights are arranged around the circumference of the log around the conveyor. The side cameras are set up to trigger only the lights that are adjacent to it. The positioning of the side cameras and lights as well as the triggering system is shown in Figure 5.

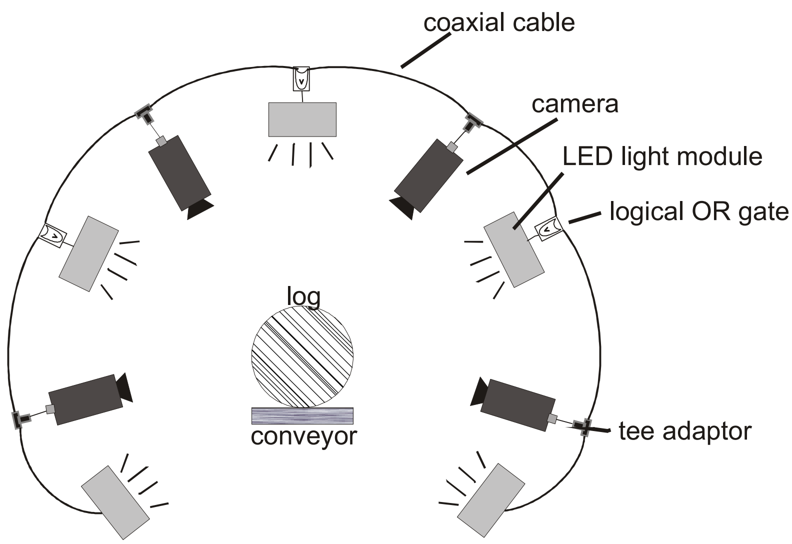

Figure 5. Side camera and lighting plus triggering

As a log approaches the system on the conveyor, the following sequence of events occurs:

1. Photodetector is triggered, informing the software that a log is coming to be profiled;
2. After the log has moved a preset distance that is defined by the user, the leading face picture is captured;
3. In order to take a full-length image of the log, multiple pictures are taken at a predefined offset;
4. Once the photogate is unblocked, i.e., the log has passed, the system waits for another predefined offset before capturing an image of the trailing end of the log;
5. Once the trailing picture is snapped, correlation is used to join the side images for each of the four logs in order to create a continuous full length image for processing.

System Calibration

The system makes geometric correlations between features captured in digital images and true shape surface scans of logs. In order to make accurate correlations between pixels in captured images placed in a true shape scan, a calibration procedure is undertaken to ensure cameras are precisely positioned and aimed. Only then can accurate mapping between camera pixel space and true shape space be made. What follows is the procedure to set up and calibrate the system.

On the bolted frame, a Manfrotto tripod allowing roll, pitch, and yaw angle changes (Figure 8) is approximately placed in each of the position where the six cameras are to be located. A camera is then mounted on each tripod.

Because there are cameras for taking side pictures, and cameras for taking log end pictures, there are two camera calibration procedures that must be undertaken.

Side Camera Calibration

A special calibration tube (Figure 6) is placed on the flights of the log conveyor in view of the four side cameras. The calibration tube is a cylinder with straight circumferential and longitudinal lines drawn on its surface. The tube is rotated so that a longitudinal line is directly on the top of the tube.

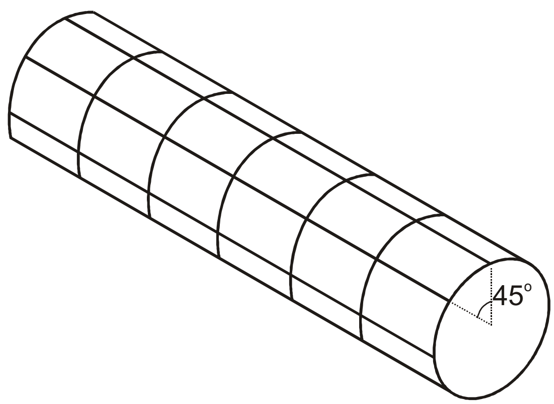

Figure 6. Calibration tube

Then, a calibration program is started on the PC, which allows each side camera's image to be viewed with a crosshair in the middle. The objective is to make each side camera squared up in all directions and pointing at exactly 45 degrees to the surface of the calibration tube, such that the crosshair on the computer screen lines up exactly with a crossing pair of lines on the calibration tube (Figure 7).

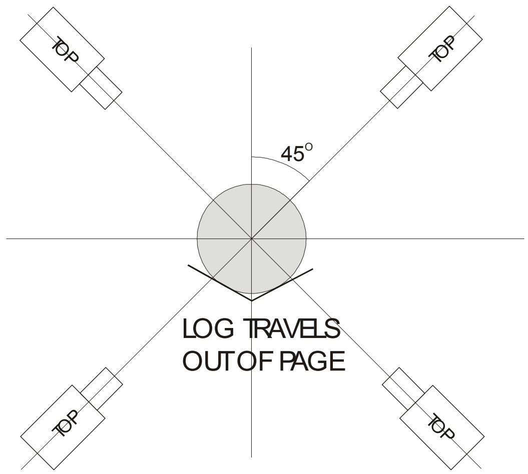

Figure 7. Orientation of side cameras after calibration

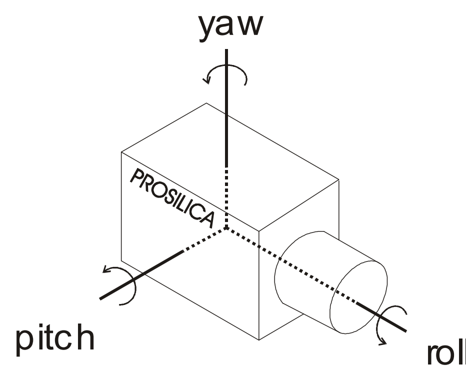

Figure 8. Camera Roll/Pitch/Yaw axes

Calibration would start with one of the four side cameras and proceed in the following manner:

1. The lens of the camera is dropped to face the ground using the yaw component;
2. The pitch is adjusted to exactly 90 degrees using a digital level, i.e., the level is placed on the camera case to ensure the camera is pitched perfectly downwards;
3. The yaw is adjusted back so that the camera lens rotates 90 degrees;
4. The roll component is then adjusted to exactly 90 degrees;
5. The yaw component is adjusted to 45 degrees to face the surface of the calibration tube;
6. With the calibration program running on the PC, the camera is moved transversely until the vertical crosshair lines up with the lengthwise line on the calibration tube;

7. The conveyor is moved until the crosswise line on the calibration tube lines up with the crosshair in the program. Now the position of the calibration tube is set and won't be touched for the rest of the routine;
8. The above procedure is then repeated for each of the side cameras with the exception of the moving of the carriage.

Front and Back Face Camera Calibration

The calibration of the cameras that capture images of the log ends is more complicated as it requires values to be obtained to correct the perspective distortion introduced by the cameras' off-axis positioning. The procedure must be performed for each of the two cameras that take pictures of log faces.

The camera must be mounted on the bolted frame that straddles the log conveyor, and pointed towards the conveyor such that it can take pictures of log faces. It should be levelled such that it has no roll with respect to the ground. At least 24 inches in height and width must be contained in the image where the log face would appear – this ensures that no part of any common log would be cropped out of the picture.

The calibration tube (Figure 6) should be placed on the log conveyor with a board with an image of a rectangular grid placed on the face of the calibration tube. The calibration tube should be levelled such that the grid is perfectly aligned with the ground.

A special calibration program must then be started on the PC. The program shows what the camera is imaging, with a set of crosshairs pained over the image. The camera must be realigned such that the crosshairs intersect at the same place as a pair of gridlines intersect on the calibration tube's grid, as shown in Figure 9.

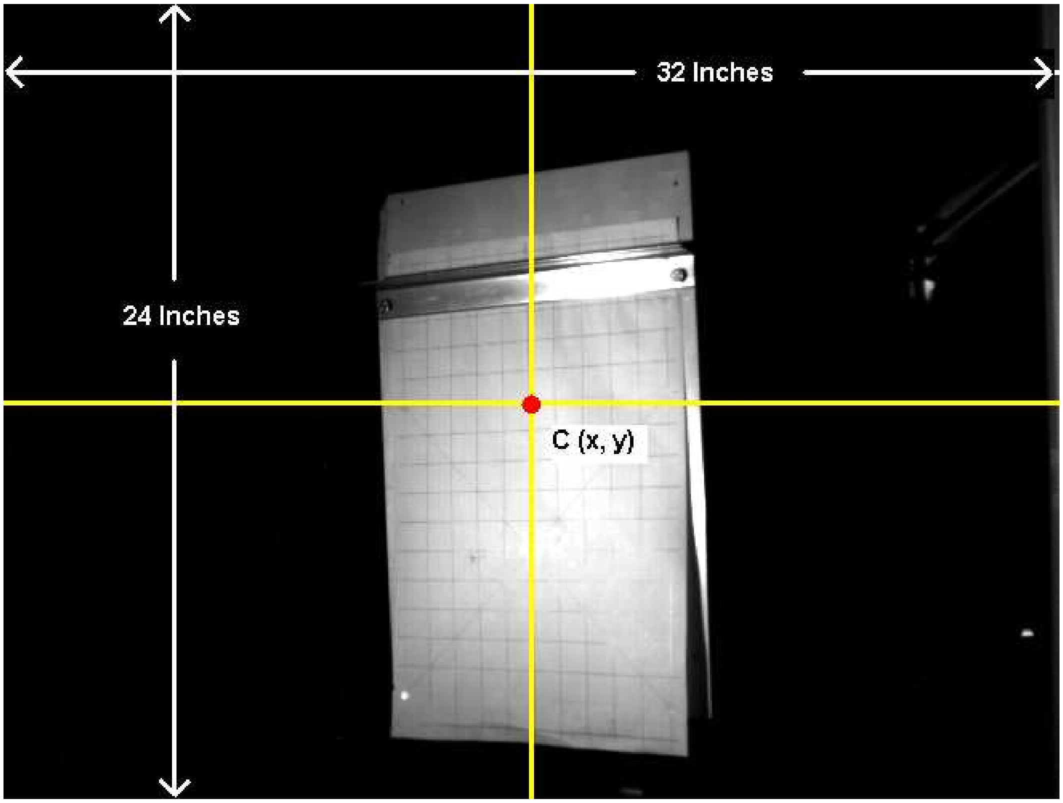

Figure 9. Alignment of log face camera to calibration grid

Then, four points are clicked in the calibration program that correspond to the four points of a square on the grid on the calibration tube (Figure 10).

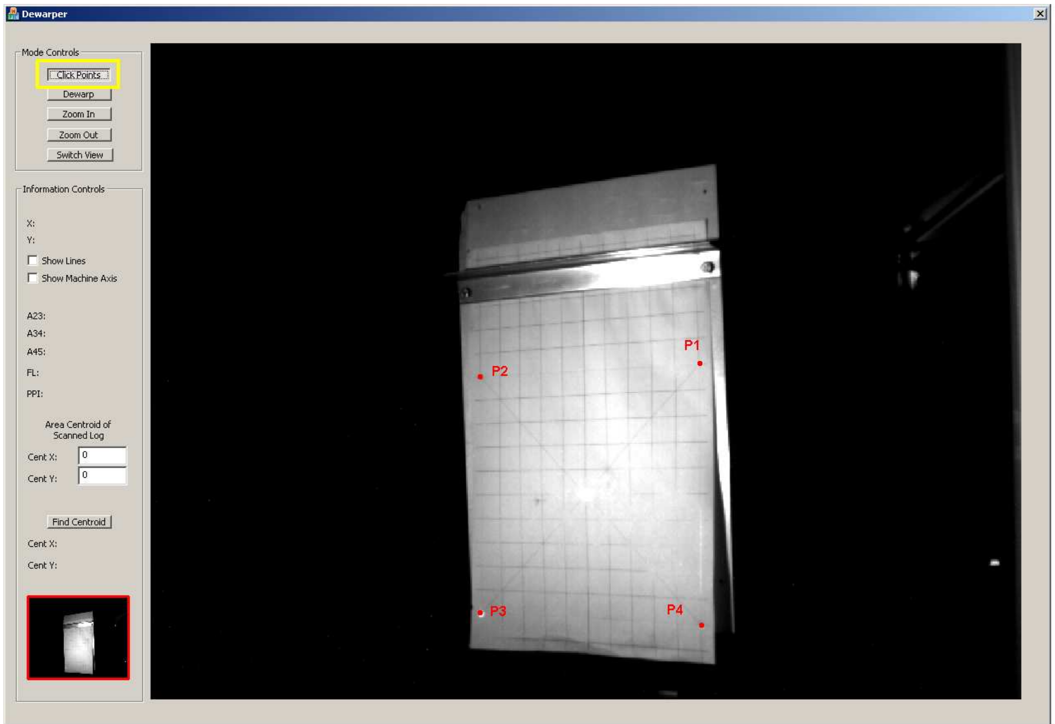

Figure 10. Clicking of the four reference points

Finally, estimates must be made of the angles by which the camera is off-axis of the log face, as well as of the camera focal length. These values are entered into the calibration program. The calibration program then uses an iterative method to refine the estimates of off-axis angles and camera focal length to their correct values. The refined values are then used to transform the off-axis warped images into dewarped images when the system runs. The dewarped image is shown in Figure 11.

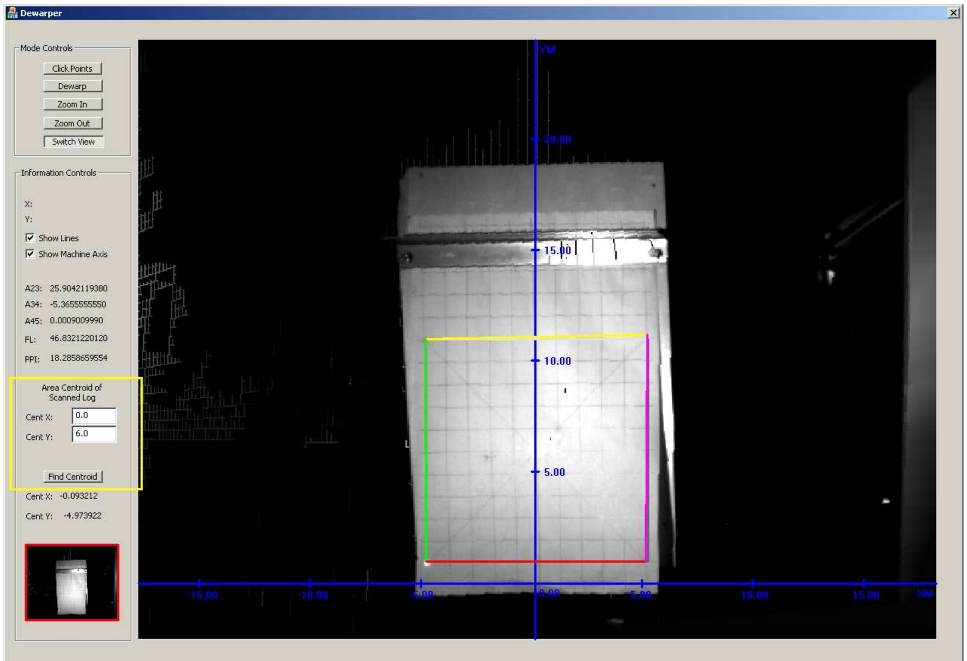

Figure 11. Dewarped image, calibrated with machine axis

LED Lighting Module Setup

With the cameras in place, the LED lighting modules are mounted and aimed at the calibration tube such that the area seen by each camera is illuminated as uniformly as possible. The brightness control on each lighting module is adjusted such that the images captured by the camera are neither too dim to see any detail, nor too bright to saturate the image.

Processing of the log surface images to identify the blue stain and check defects

This processing has been done using image processing software in the following steps:

A. The digital pictures of the log leading and trailing end faces were processed as follows:

1. dewarping - i.e., correcting for the perspective off-axis viewing distortion;
2. scaling and positioning – i.e., converting from camera chip pixel units into inches, and repositioning the picture from the camera coordinate system into the machine coordinate system;
3. reading and recording the log number from the tag stapled to the log face;
4. image processing to identify the log face edges, blue stain boundary, and the checks;

5. storing the edited data points (for this log# and the leading/trailing end faces) in the database.

B. Each of the four sets of digital pictures of the log side surfaces were processed as follows:

1. scaling – i.e., converting from camera chip pixel units into inches along the log length;
2. image processing software to identify log side edges and the checks (the blue stain areas on the log sides cannot be detected);
3. image processing to “map”, or “project”, the above data onto the true shape of the log as collected by the mill true shape laser scanning system;
4. storing the edited data points (for this log# and the particular side) in the database.

Performance Verification at Forintek

Five stems from the sample, with blue stain and check defects, were provided by Tolko Meritt sawmill. There the stems were bucked into approximately nine 20-foot long logs and debarked, and then trucked to Forintek to ascertain correct functioning of the defect detection system. At Forintek these logs were bucked into 10-foot long logs, and each log was identified by unique tags stapled to the log faces to ensure that the image of the original stem can be re-assembled, with the logs in the correct sequence and rotational position. Then, using a forklift, each log was loaded onto the Forintek linear scanning system carriage and conveyed through the machine vision and true shape laser scanning systems. The digital pictures that were collected by the machine vision system were then processed by the image processing software to identify the blue stain and check defects. The defects were then “mapped” onto the log images that were collected by the true shape laser scanning system. The locations and sizes of these defects were then compared with the actual defects on the (real) logs. The differences (i.e., errors) between the two were found to be acceptable for the needs of this project.

Performance Verification using Forintek/UNBC CT Scanner

The Forintek Canada Corp./UNBC CT scanner was used to scan one complete stem consisting of five logs. These scans provided us with a detailed look at what the internal structure of the logs were and how the checks actually propagated down a given log. Below is a comparison between the different media confirming the viability of data.

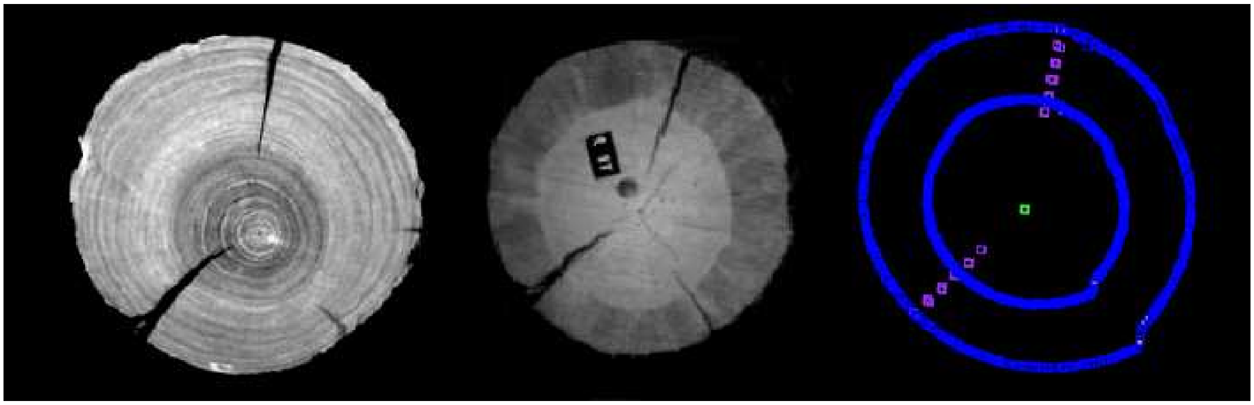

Figure 12. Left to Right: CT scan, Picture Taker, Optitek® Ready Data

Above are the three unedited forms of data. On the left is the CT Scan that is close to the log end shown in the middle picture. The far right picture shows the point data coming out that is used for Optitek® generation. Below are the scaled and rotated images that show the accuracy of the test data.

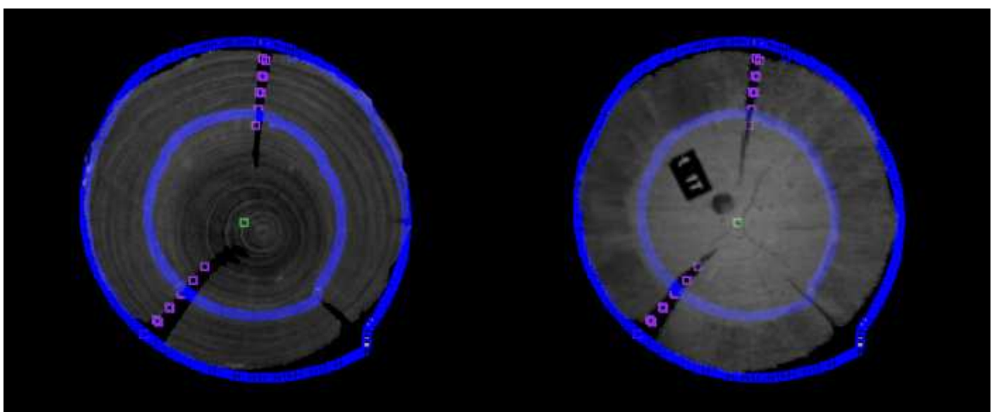

Figure 13. Left to Right: CT scan comparison, Picture Taker comparison

The images in Figure 12 were rotated and scaled slightly and shown in Figure 13. It can be seen on the left that the Optitek® data matches very closely to the CT scan taken at that level. On the right hand side of the above figure, the match is close to perfect. This shows that the data that is being extracted is in fact a good representation of what the real data is.

These test logs also provided a good knowledge base for the effects on CT scanning a completely dry log. Below is the other end of the same log as shown previously.

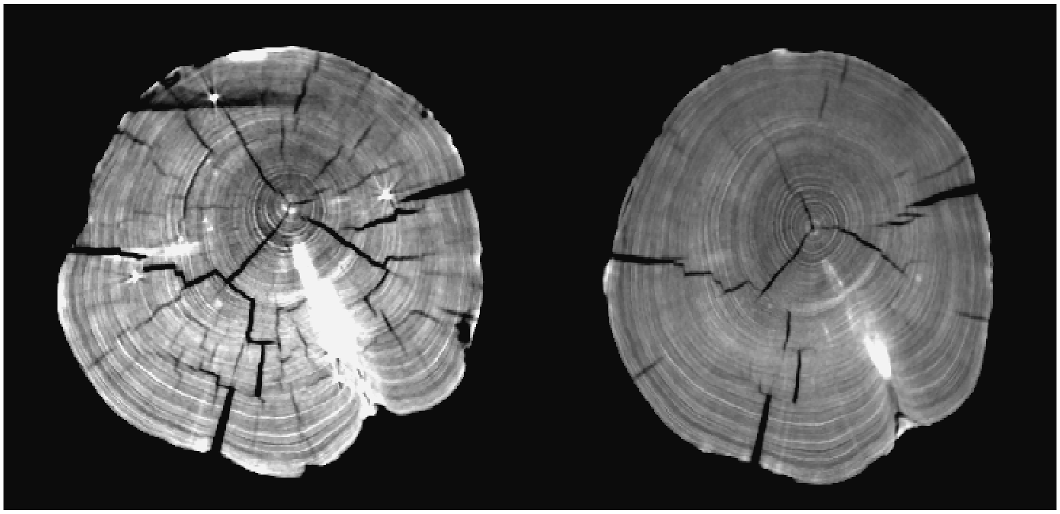

Figure 14. Left - Severely checked log cross section due to drying

Figure 15. Right - Approximately 16" further into the log

The CT scans shown in Figure 14 and Figure 15 suggests that a completely dried log is not representative of what would be found in a typical mill environment. In Figure 15, it can be seen that many of the checks are not present. If this log was not completely dried, many of the checks would not be visible on the surface and no strictly surface scanning vision system would be able to identify a closed check. This is one of the limitations of a vision system. If the moisture content were above normal, checks that would have been identifiable would appear not to exist to a vision system. However, for logs that do have visible checks this system could be tailored to identify these checks.

Performance limitations

The grey scale digital pictures made by Forintek check and stain detection system were such that the human editors and/or image processing software could identify blue stain boundaries on the cleanly bucked (sawn) log faces in most cases nearly perfectly, and checks larger than approximately .10 inches in width could be identified with high reliability. However, the following limitations were encountered:

- Blue stain areas on (debarked) log sides cannot be identified with any useful accuracy even in full colour images.
- Blue stain areas on undebarked log sides cannot be identified at all.
- Identification of checks on the leading log face was made more difficult by the "score marks" that are made by the debarker tools as the leading ends of logs enter the debarker. The number of these score marks is equal to the number of the debarker tools (usually six). The marks are equally

spaced and start near the log centre, and arc slightly toward the log perimeter, and as such are similar in appearance to (radial) checks.

- If the log faces are not cleanly cut, are dirty, or are covered with snow or ice, it may not be possible to identify the blue stain and checks.
- Some smaller checks in the log faces have been caused by localized drying of log ends, and therefore these checks extend only a short distance into the log – as compared to long checks resulting from drying of the entire log. The short checks have much smaller impact on lumber recovery, and hence must not be misinterpreted as the long checks.
- Checks larger than approximately .20 inches in width, on well debarked log sides could be identified with high reliability.
- Checks on debarked log sides could not be identified in the cat face areas and inadequately debarked areas.
- As previously noted, because of (very likely) possible rehydration of logs, the check width on the log sides is not a good predictor of check depth if the extent of rehydration is not known. This deficiency may be overcome for those logs having checks on the log faces, and then from their width-to-depth ratio the extent of rehydration may be inferred.
- Visual identification of checks on undebarked log sides is very difficult as the checks remain generally partly covered by the bark, and the texture of pine bark has longitudinal striations similar to checks. Only checks wider than .30 inches can be identified reliably.
- Not surprisingly, human editors can manually identify blue stain boundary and checks more reliably than image processing software, but it is quite time consuming. The current image processing software works well (and instantly) in identifying blue stain boundary and checks on the log faces. It does not work well on identifying checks on the log sides, but it is likely that this can be improved with further development – at least for the wide checks.
- Due to the monochrome images as well as the range of logs that needed to be profiled (7 inches to 18 inches), the pith was very difficult to identify for the smaller logs.

The above “problems” will also likely be encountered by similar systems that the technology providers and manufacturers may market to the sawmills processing mountain pine beetle-killed timber.

Appendix 4: Dimensional Data of Sample

Basic dimensional data of the logs used in the sample are presented here along with basic statistical data.

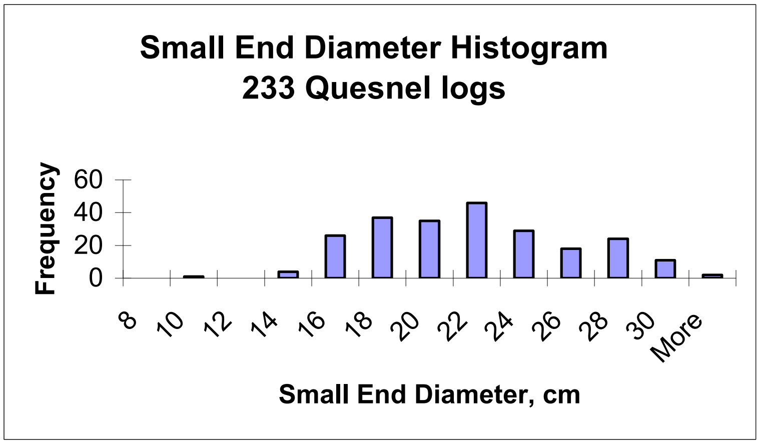

Figure 16. Small end diameter histogram

Table 3. Dimensional data of 233 log sample

Log #	Average Small End Diameter (cm)	Average Large End Diameter (cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Length (m)
1	15.90	21.06	0.61	1.16	4.45
2	18.49	24.32	0.53	1.34	4.35
3	16.79	20.98	0.16	0.85	4.95
4	20.09	27.15	0.72	2.11	3.35
5	17.65	23.47	1.10	1.82	3.20
6	16.03	17.86	0.73	0.61	3.00
7	17.65	23.47	1.10	1.82	3.20
8	16.38	19.13	0.42	0.93	2.95
9	16.79	20.98	0.16	0.85	4.95
10	20.88	25.91	0.78	1.57	3.20
11	16.79	20.98	0.16	0.85	4.95
12	17.30	23.08	0.40	1.09	5.30
13	16.12	21.11	0.43	1.58	3.15
14	18.01	19.67	0.49	0.53	3.15
15	21.24	23.32	0.30	0.69	3.00
16	29.23	31.73	0.67	0.68	3.66
17	20.09	27.15	0.72	2.11	3.35
18	22.23	23.52	0.25	0.43	3.00
19	20.09	27.15	0.72	2.11	3.35

Log #	Average Small End Diameter (cm)	Average Large End Diameter (cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Length (m)
20	19.18	20.31	0.86	0.34	3.35
21	17.65	23.47	1.10	1.82	3.20
22	15.82	21.43	0.56	1.38	4.05
23	19.89	22.10	0.54	0.70	3.15
24	22.23	23.52	0.25	0.43	3.00
25	15.98	16.90	0.49	0.29	3.20
26	16.38	19.13	0.42	0.93	2.95
27	15.82	21.43	0.56	1.38	4.05
28	21.24	23.32	0.30	0.69	3.00
29	19.89	22.10	0.54	0.70	3.15
30	20.88	25.91	0.78	1.57	3.20
31	15.90	21.06	0.61	1.16	4.45
32	14.91	19.59	0.75	1.36	3.45
33	15.98	16.90	0.49	0.29	3.20
34	19.89	22.10	0.54	0.70	3.15
35	20.09	27.15	0.72	2.11	3.35
36	18.62	19.96	0.52	0.43	3.15
37	17.65	23.47	1.10	1.82	3.20
38	15.82	21.43	0.56	1.38	4.05
39	17.30	23.08	0.40	1.09	5.30
40	19.89	22.10	0.54	0.70	3.15
41	17.30	23.08	0.40	1.09	5.30
42	21.62	24.28	0.61	0.85	3.15
43	19.81	22.72	0.33	0.89	3.25
44	20.88	25.91	0.78	1.57	3.20
45	18.62	19.96	0.52	0.43	3.15
46	18.01	19.67	0.49	0.53	3.15
47	17.65	23.47	1.10	1.82	3.20
48	21.24	23.32	0.30	0.69	3.00
49	20.88	25.91	0.78	1.57	3.20
50	21.29	22.46	0.50	0.39	3.00
51	14.52	17.85	0.71	0.66	5.05
52	19.81	22.72	0.33	0.89	3.25
53	15.82	21.43	0.56	1.38	4.05
54	20.09	27.15	0.72	2.11	3.35
55	13.51	20.17	0.81	1.73	3.85
56	20.68	22.45	1.09	0.53	3.35
57	22.23	27.99	0.90	1.70	3.38
58	17.30	23.08	0.40	1.09	5.30
59	26.59	28.63	0.31	0.56	3.65
60	19.89	22.10	0.54	0.70	3.15
61	18.01	19.67	0.49	0.53	3.15
62	29.97	36.65	0.66	1.07	6.23

Log #	Average Small End Diameter (cm)	Average Large End Diameter (cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Length (m)
63	26.40	34.63	0.60	1.35	6.10
64	20.88	25.91	0.78	1.57	3.20
65	20.88	25.91	0.78	1.57	3.20
66	21.24	23.32	0.30	0.69	3.00
67	15.90	21.06	0.61	1.16	4.45
68	20.68	22.45	1.09	0.53	3.35
69	22.58	25.76	0.67	1.01	3.15
70	22.23	23.52	0.25	0.43	3.00
71	22.58	25.76	0.67	1.01	3.15
72	20.88	25.91	0.78	1.57	3.20
73	18.49	24.32	0.53	1.34	4.35
74	20.88	25.91	0.78	1.57	3.20
75	20.09	27.15	0.72	2.11	3.35
76	17.65	23.47	1.10	1.82	3.20
77	18.87	25.43	0.32	1.58	4.15
78	20.88	25.91	0.78	1.57	3.20
79	18.01	19.81	0.92	0.60	3.00
80	22.57	24.69	0.59	0.44	4.80
81	19.89	22.10	0.54	0.70	3.15
82	20.88	25.91	0.78	1.57	3.20
83	20.68	22.45	1.09	0.53	3.35
84	21.24	23.32	0.30	0.69	3.00
85	16.03	17.86	0.73	0.61	3.00
86	20.09	27.15	0.72	2.11	3.35
87	28.83	32.61	0.35	1.17	3.25
88	19.81	22.72	0.33	0.89	3.25
89	18.49	24.32	0.53	1.34	4.35
90	16.79	20.98	0.16	0.85	4.95
91	17.65	23.47	1.10	1.82	3.20
92	21.24	23.32	0.30	0.69	3.00
93	21.29	22.46	0.50	0.39	3.00
94	14.44	20.15	1.41	1.91	3.00
95	17.65	23.47	1.10	1.82	3.20
96	21.24	23.32	0.30	0.69	3.00
97	18.78	21.06	0.27	0.61	3.75
98	17.30	23.08	0.40	1.09	5.30
99	16.70	20.89	0.38	1.27	3.30
100	19.89	22.10	0.54	0.70	3.15
101	8.81	19.06	1.26	2.77	3.70
102	26.40	34.63	0.60	1.35	6.10
103	22.28	25.21	0.52	0.89	3.30
104	15.82	21.43	0.56	1.38	4.05
105	22.28	25.21	0.52	0.89	3.30

Log #	Average Small End Diameter (cm)	Average Large End Diameter (cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Length (m)
106	25.55	30.38	0.52	1.07	4.49
107	26.40	34.63	0.60	1.35	6.10
108	16.05	20.14	0.54	1.30	3.15
109	26.86	35.51	0.72	1.41	6.15
110	28.83	32.61	0.35	1.17	3.25
111	25.24	32.28	0.61	1.15	6.15
112	26.40	34.63	0.60	1.35	6.10
113	29.97	36.65	0.66	1.07	6.23
114	30.07	36.81	0.41	1.08	6.24
115	20.09	27.15	0.72	2.11	3.35
116	22.23	27.99	0.90	1.70	3.38
117	26.59	28.63	0.31	0.56	3.65
118	20.91	27.76	0.96	1.56	4.40
119	29.23	31.73	0.67	0.68	3.66
120	25.24	32.28	0.61	1.15	6.15
121	21.96	25.10	0.56	1.06	2.95
122	22.57	24.69	0.59	0.44	4.80
123	28.59	37.34	0.50	2.01	4.36
124	26.81	32.69	0.30	0.95	6.21
125	24.03	25.96	0.56	0.59	3.25
126	25.24	32.28	0.61	1.15	6.15
127	26.85	30.07	0.76	0.72	4.49
128	26.86	35.51	0.72	1.41	6.15
129	21.69	24.66	0.55	0.68	4.35
130	26.85	30.07	0.76	0.72	4.49
131	25.24	32.28	0.61	1.15	6.15
132	27.08	35.23	0.74	1.30	6.28
133	25.24	32.28	0.61	1.15	6.15
134	19.84	23.52	0.37	1.23	3.00
135	26.59	28.63	0.31	0.56	3.65
136	25.24	32.28	0.61	1.15	6.15
137	20.09	27.15	0.72	2.11	3.35
138	28.83	32.61	0.35	1.17	3.25
139	25.24	32.28	0.61	1.15	6.15
140	14.53	23.77	1.12	2.61	3.55
141	23.04	24.07	0.75	0.35	2.95
142	26.59	28.63	0.31	0.56	3.65
143	23.37	26.06	0.28	0.90	3.00
144	26.86	35.51	0.72	1.41	6.15
145	17.35	25.53	0.20	1.51	5.40
146	26.40	34.63	0.60	1.35	6.10
147	22.91	25.96	0.65	0.92	3.30
148	22.23	27.99	0.90	1.70	3.38

Log #	Average Small End Diameter (cm)	Average Large End Diameter (cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Length (m)
149	25.40	27.70	0.76	0.57	4.01
150	29.97	36.65	0.66	1.07	6.23
151	22.57	24.69	0.59	0.44	4.80
152	29.23	31.73	0.67	0.68	3.66
153	24.12	32.99	0.52	1.43	6.19
154	28.59	37.34	0.50	2.01	4.36
155	30.07	36.81	0.41	1.08	6.24
156	25.15	28.07	0.44	0.77	3.82
157	27.08	35.23	0.74	1.30	6.28
158	26.59	28.63	0.31	0.56	3.65
159	25.35	28.53	0.37	0.72	4.40
160	26.81	32.69	0.30	0.95	6.21
161	23.19	27.29	0.74	0.66	6.22
162	16.38	19.13	0.42	0.93	2.95
163	25.55	30.38	0.52	1.07	4.49
164	27.81	34.42	1.42	1.62	4.08
165	26.85	30.07	0.76	0.72	4.49
166	26.90	35.97	1.26	1.47	6.17
167	21.90	26.75	0.71	0.98	4.93
168	20.03	25.17	0.61	0.97	5.30
169	26.86	35.51	0.72	1.41	6.15
170	15.04	26.11	0.55	2.09	5.30
171	21.03	24.72	1.13	0.59	6.25
172	15.90	21.06	0.61	1.16	4.45
173	19.58	22.22	0.72	0.74	3.55
174	23.42	25.93	0.76	0.79	3.20
175	16.00	20.71	0.39	1.21	3.90
176	20.98	23.72	0.92	0.87	3.15
177	22.99	25.79	0.41	0.89	3.15
178	25.24	32.28	0.61	1.15	6.15
179	22.83	26.44	0.46	0.98	3.70
180	17.32	21.22	0.38	1.16	3.35
181	14.92	18.23	0.55	0.71	4.65
182	17.35	25.53	0.20	1.51	5.40
183	18.62	19.96	0.52	0.43	3.15
184	13.72	17.53	0.94	1.21	3.15
185	20.64	27.48	0.62	1.56	4.40
186	19.89	22.10	0.54	0.70	3.15
187	17.30	23.08	0.40	1.09	5.30
188	21.96	25.10	0.56	1.06	2.95
189	14.58	19.23	0.92	1.48	3.15
190	22.91	25.96	0.65	0.92	3.30
191	19.18	25.19	0.65	1.77	3.40

Log #	Average Small End Diameter (cm)	Average Large End Diameter (cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Length (m)
192	17.17	20.90	0.77	0.63	5.90
193	17.65	23.47	1.10	1.82	3.20
194	18.01	19.81	0.92	0.60	3.00
195	13.69	18.76	0.92	1.07	4.75
196	21.24	23.32	0.30	0.69	3.00
197	19.84	23.52	0.37	1.23	3.00
198	14.52	17.85	0.71	0.66	5.05
199	19.91	21.95	0.99	0.67	3.05
200	22.83	24.47	0.54	0.54	3.00
201	23.37	26.06	0.28	0.90	3.00
202	16.79	20.98	0.16	0.85	4.95
203	22.28	25.21	0.52	0.89	3.30
204	23.04	24.07	0.75	0.35	2.95
205	15.98	16.90	0.49	0.29	3.20
206	16.03	17.86	0.73	0.61	3.00
207	16.71	17.88	0.50	0.40	2.90
208	23.57	24.61	0.58	0.33	3.10
209	14.91	19.59	0.75	1.36	3.45
210	15.69	20.35	1.24	1.55	3.00
211	14.44	20.15	1.41	1.91	3.00
212	16.12	21.11	0.43	1.58	3.15
213	18.78	21.06	0.27	0.61	3.75
214	13.51	20.17	0.81	1.73	3.85
215	24.62	26.86	0.27	0.76	2.95
216	22.66	24.64	0.37	0.63	3.15
217	15.82	21.43	0.56	1.38	4.05
218	24.38	26.20	0.53	0.54	3.35
219	14.94	19.72	0.70	1.47	3.25
220	20.68	22.45	1.09	0.53	3.35
221	21.61	24.26	0.47	0.82	3.25
222	20.88	25.91	0.78	1.57	3.20
223	22.63	26.95	0.49	1.46	2.95
224	23.80	26.26	0.73	0.82	3.00
225	19.00	21.06	0.74	0.68	3.05
226	21.29	22.46	0.50	0.39	3.00
227	19.18	20.31	0.86	0.34	3.35
228	18.37	20.55	0.96	0.65	3.35
229	24.03	25.96	0.56	0.59	3.25
230	16.12	21.11	0.43	1.58	3.15
231	18.01	19.67	0.49	0.53	3.15
232	16.38	19.13	0.42	0.93	2.95
233	26.40	34.63	0.60	1.35	6.10
Avg:	20.83	25.15	0.62	1.08	3.94

Log #	Average Small End Diameter (cm)	Average Large End Diameter (cm)	Average Sweep (cm/m)	Average Taper (cm/m)	Length (m)
Min:	8.81	16.90	0.16	0.29	2.90
Max:	30.07	37.34	1.42	2.77	6.28
StDev:	4.18	4.94	0.25	0.50	1.10

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