AN ALGORITHM FOR LOG ROTATION IN SAWMILLS

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ABSTRACT

Great strides have been made in sawmill automation since the first Best Opening Face (BOF) models were proposed in the 1970s. For example, curve sawing techniques have demonstrated strong potential in maximizing the value recovery from sawmills. This paper concerns an important step in maximizing lumber yield in a sawmill, namely *log rotation*. Rotating the logs to be in the *horns up* or *horns down* position just before the sawing process has been shown to have a positive effect on maximizing the lumber yield. We present an efficient algorithm that, upon being fed the appropriate scan data for a log in an arbitrary position, determines the necessary angle of rotation for the log to be oriented (in real-time) in the *horns up* or *horns down* position.

Keywords: Log rotation, algorithm, sawmill.

SOME HISTORY AND MOTIVATION

In light of society's continued dependence on wood and forest products, it is imperative that sawmills and other forest products companies process the available forest resources in the most efficient manner. Consequently, optimization techniques are continually being improved so that the loss of value recovery from sawmills is minimized. Computer automation plays a pivotal role in this important endeavor. During the days when sawing optimization systems were just beginning to develop, the focus was primarily on log diameter, length, and taper in the determination of the ideal log opening face position (see Hallock and Lewis 1971; Harpole and Hallock 1977; Lewis 1985; and Shi et al. 1990). In other words, important considerations like log sweep and crook were not yet being considered. This is not to say that sawing accuracy was not an issue (see Stern et al. 1979). As a result, such optimization models were most effective only when the log classes did not demonstrate these other characteristics (log sweep and crook). The most well known of these models, the Best Opening Face (BOF) (Lewis 1985) was originally developed to study the effect of these factors on lumber yield; but it is now widely used in management planning, engineering and design, automated control systems, and evaluating operating efficiency. The BOF model is a simulation of the actual sawing process. A log scanner determines the diameter, taper, and length of a log that is fed to the BOF model. The model first determines the initial opening face that will produce the smallest acceptable piece from that log, and then successive cuts are made from which the yield for the log can be determined. The process is repeated by moving the opening face toward the center of the log. This continues until all reasonable possibilities have been considered, after which the Best Opening Face is chosen to maximize yield.

Although the BOF model has been greatly

simplified by Steele et al. (1987) under these assumptions, there is still the problem of how to best simulate the complex profiles of real logs and study the effects of various factors on yield. In light of this issue, it has been demonstrated (Wang et al. 1992) that in addition to the log characteristics stated above, sweep, cant-size selection, and *log rotation* are also significantly correlated with lumber recovery.

Although there are many methods for dealing with log sweep (see Maness and Donald 1994), the most cutting-edge procedure utilizes curve sawing (Hasenwinkle et al. 1987; Lindstrom 1979) wherein, a two-sided cant that follows the curve in the log is cut. This is accomplished by turning the log to the *horns up* or *horns down* (more often, it is *horns down*) position upon which the cant is sawn with a variable curve linebar. It should be noted that these days, this operation is carried out by circular gang saws. While it is intuitively clear that imprecise manual log rotation has a negative effect on the lumber recovery, the authors in Wang et al. (1992) use a regression approach to predict the percentage drop-off in lumber recovery from manual log rotation. As a matter of fact, even in the early days of sawing optimization, it was recognized by Richards et al. (1980) that the most important decision made by the sawyer is the rotational position of the log on the carriage for the first cut. With the aid of advanced scanners and other automation equipment, the gap between theorized solutions and practical implementability should draw closer. As is commonly acknowledged, full shape, three-dimensional scanning has the potential for affecting a marked improvement on value recovery. However, our algorithm uses only the data concerning the x- and y-coordinates of the center points, which are calculated from the scan data. Specifically, the data used in this paper were procured from a Hermary™ (model HDS-050) 2-axis scanner.

Furthermore, in this paper, we focus on an important step in straight (or conventional) sawing, wherein the log is first rotated to the *horns up* or *horns down* position, before a straight saw obtains a cant that is parallel to the plane of the cutter blades. The reason for trying to achieve a *horns up* or *horns down* position in straight sawing is so that most of the sweep is contained in a plane parallel to the axis of the conveyor, which results in higher yield when followed by a curved saw. On the other hand, if a log is a perfect right cylinder, then one would not require any rotation. However, our project involved a random sample of logs that belong to the southern yellow pine species. As is well-known, these are softwood species that are noted for sweepy characteristics. Consequently, for straight sawing, a *horns up* or *horns down* orientation (before sawing) is greatly desired. Essentially, by doing so, one forces the sweep to be contained in the plane of the cutter blades and hence the yield is higher. While many existing software programs already perform this task, we present an extremely efficient, real-time algorithm that will rotate a log from an arbitrary position on the conveyor, to being *horns up* or *horns down.*

CHANGE OF COORDINATES UNDER ROTATION

In their quest to align a log in the *horns up* or *horns down* position, the rollers rotate the log about an axis that is parallel to the conveyor and passing through a "pivot" point P_{piv}. In other words, the log is rotated about the point P_{piv}. In practice, the point P_{piv} is chosen as one of the cross-sectional centers obtained from the scan data. The stability of the operation is a crucial consideration when choosing the location of the pivoting point P_{piv}. In fact, we have studied the effect (on the accuracy of the rotation) produced by varying the location of the pivot point along the length of the log. Furthermore, it is important to note that unless a typical point P_{orig} (on the log) lies on the axis of rotation, turning the log through an angle α would move P_{orig} to a new point P_{rot}. This section is devoted to understanding the mathematics of rotation so that we may determine the coordinates of the new point P_{rot}. We will use a classical technique from

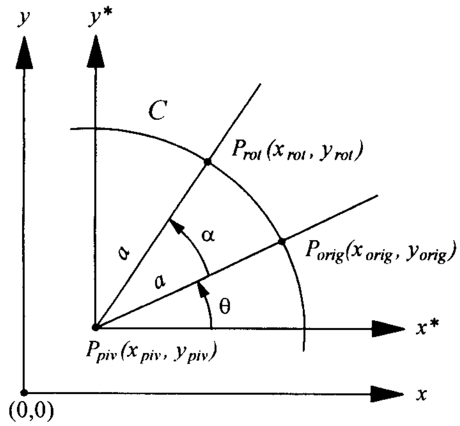

FIG. 1. Change of coordinates under rotation.

polar coordinate geometry (see Thomas 1960) to determine the new coordinates.

First, we establish some notation. Throughout this paper, $P_{piv}(x_{piv}, y_{piv})$ will denote the pivot point for the rotation, $P_{orig}(x_{orig}, y_{orig})$ the point *before* rotation, $P_{rot}(x_{rot}, y_{rot})$, the point *after* rotation, and α the measure of the angle of rotation in the counter clockwise direction as the log is faced head-on. We observe that a convenient way to understand the effect of rotation on the coordinates of a point is to move the origin from the location (0, 0) to the point P_{piv}. Essentially, we are translating the original coordinate axes (denoted by xy in Fig. 1) to new coordinate axes (denoted by x^*y^* in Fig. 1) so that the origin of the x^*y^* coordinate system is the point P_{piv}, and the horizontal and vertical axes, respectively, of the two coordinate systems remain parallel. As shown in Fig. 1, let θ be the angle between the positive x-axis and the line segment joining the points P_{piv} and P_{orig}. Furthermore let a denote the length of the segment joining P_{piv} and P_{orig}.

It is easy to see that under the x^*y^* coordinate system, the point P_{orig} may be represented as the point $P_{orig}(x_{orig} - x_{piv}, y_{orig} - y_{piv})$. Similarly, the point P_{rot} may be represented as the point $P_{rot}(x_{rot} - x_{piv}, y_{rot} - y_{piv})$. Note that the points P_{orig} and P_{rot} lie on a circle C (see Fig. 1) centered at the point P_{piv}. By representing the points P_{orig} and P_{rot} using polar coordinates, we have the following equations:

$$x_{orig} - x_{piv} = a \cos \theta \tag{1}$$

$$y_{orig} - y_{piv} = a \sin \theta \tag{2}$$

$$x_{rot} - x_{piv} = a \cos(\theta + \alpha) \tag{3}$$

$$y_{rot} - y_{piv} = a \sin(\theta + \alpha). \tag{4}$$

Using the sum formulae for the sine and cosine functions in Eqs. (3) and (4), respectively, we have

$$x_{rot} - x_{piv} = (a \cos \theta)\cos \alpha - (a \sin \theta)\sin \alpha \tag{5}$$

$$y_{rot} - y_{piv} = (a \cos \theta)\sin \alpha + (a \sin \theta)\cos \alpha. \tag{6}$$

Substituting Eqs. (1) and (2) in (5) and (6), respectively, yields the following coordinates for the point P_{rot}:

$$x_{rot} = (x_{orig} - x_{piv})\cos \alpha - (y_{orig} - y_{piv})\sin \alpha + x_{piv} \tag{7}$$

and

$$y_{rot} = (x_{orig} - x_{piv})\sin \alpha + (y_{orig} - y_{piv})\cos \alpha + y_{piv}. \tag{8}$$

Note that the change of coordinates equations are independent of the angle θ.

THE ALGORITHM FOR LOG ROTATION

The data available from a scanner like the Hermary™ (model HDS-050) 2-axis scanner used in this study provide the log diameters $x_{diam,i}$ and $y_{diam,i}$, $i = 1 \ldots n$ in the x and y directions, respectively, where n is the number of *slices* of data. Slices are typically located about three inches apart. The location of the left edge of the slice, $x_{edge,i}$, and the bottom edge $y_{edge,i}$ are also provided. From these data, one can estimate the slice center using the equations $x_{cent,i} = x_{edge,i} + (x_{diam,i})/2$ and $y_{cent,i} = y_{edge,i} + (y_{diam,i})/2$. A three-dimensional model of the log may be interpolated from the above data; however, our approach is much simpler. The basic idea of the algorithm is to rotate the centers of each slice by an angle at which the new locations of the centers are *closest* (in the x-direction) to the imaginary axis that the log rotates about. Intuitively speaking, we are trying to *look down* on the log as it lies on the conveyor (the xz plane, where the z-axis runs along the length of the log) and rotate it so that it *best* lines up with the axis of rotation. Thus, the rotated centers $x_{rot,i}$ and $y_{rot,i}$ (for a specified α and pivot point P_{piv}) are obtained by substituting $x_{cent,i}$ for x_{orig} and $y_{cent,i}$ for y_{orig} in Eqs. (7) and (8), respectively above.

It should be noted that the location of the pivot point along the length of the log does affect the criterion discussed below. This is discussed in detail in a future paper. Further, note that the y-coordinate of a slice center, $y_{cent,i}$, is not relevant in determining how close a slice is to the rotation axis. However, the y-coordinate does influence the x-coordinate of a point upon rotation (refer to Eq. (7)). By rotating the log to the *horns up* (or *horns down*) position, we are forcing the sweep to be contained in the y direction (as much as possible), and thus some deviation in the y direction should be expected. With this as our motivation, we choose to measure the closeness of the rotated slices to the pivot point, as the sum of absolute deviations, $SAD = \sum_{i=1}^{n} |x_{cent,i} - x_{piv}|$. The quantity SAD minimized over α is used as the criterion to select an angle α^* that minimizes the SAD. A number of other criteria are possible, such as the classical, sum of squared deviations; however the SAD has intuitive appeal and worked best in preliminary testing.

We consider a discrete approximation to this problem by iterating over an angle α, $\alpha = 0°$, . . . , 179° at one-degree increments. It is not required that rotation be done for the full 360 degrees because under the assumptions of the preceding section, there is symmetry in the rotation with respect to the SAD criterion. Thus, the log will be either *horns up* or *horns down*. Also, one-degree increments were chosen because this is well within the degree of accuracy with which a log can be physically rotated. The algorithm is as follows:

1. Compute slice centers $(x_{cent,i}, y_{cent,i})$.
2. Choose a pivot point x_{piv}, y_{piv}.
3. Loop over $\alpha = 0°, 1°, \ldots, 179°$.
   3a. Compute rotated centers, $x_{rot,i}, y_{rot,i}$, $i = 1, \ldots, n$.
   3b. Compute SAD.
4. Choose α that minimizes SAD. This is the desired value α^*.

The advantage of this approach over a more complicated, value recovery approach is that the algorithm is $O(n)$ and thus can be executed extremely quickly on a computer.

EXAMPLES

In practice, if all the centers of the cross sections obtained from the scan data are contained in a line, then for straight sawing, one would not require any rotation. So, without loss of generality, assume that the slice centers are not collinear. We now classify logs into two categories: *planar* and *non-planar*. A log is said to be *planar* if all its n slice centers (obtained from the scanner) denoted by the triples $(x_{cent,i}, y_{cent,i}, z_{cent,i})$, $i = 1, \ldots, n$, are contained in a plane $\mathcal{P}$ in 3-space; otherwise, the log is said to be *non-planar*.

Observation: For any log, $\min_\alpha\{SAD\} = 0$ if and only if the log is planar. Furthermore, α^* is equal to the angle between the plane, $\mathcal{P}$ containing the centers of the log, and the plane given by the equation $x = x_{piv}$.

Proof of Observation: First assume that for a given log, $\min_\alpha\{SAD\} = 0$ and let α^* denote a value of α that results in $SAD = 0$. In other words, when $\alpha = \alpha^*$,

$$\sum_{i=1}^{n} |x_{cent,i} - x_{piv}| = 0. \quad (9)$$

This implies that for each $i = 1, \ldots, n$,

$$|x_{cent,i} - x_{piv}| = 0. \quad (10)$$

Hence for each $i = 1, \ldots, n$, $x_{cent,i} = x_{piv}$. Since x_{piv} is fixed for each log, it follows that the log is planar and the plane $\mathcal{P}$ is given by the equation $x = x_{piv}$.

Conversely, assume that the given log is planar and let $\mathcal{P}$ denote the plane containing all the slice centers. Let $\alpha°$ (counterclockwise) denote the angle between the planes $\mathcal{P}$ and $x = x_{piv}$. When the log is rotated by an angle $\alpha°$ (counterclockwise), the plane $\mathcal{P}$ is parallel to the plane $x = x_{piv}$. Hence $x_{cent,i} = x_{piv} \forall i = 1, \ldots, n$. This implies that for the angle $\alpha°$, $SAD = 0$. Finally, since $SAD \geq 0$, it is clear that the algorithm, which seeks the angle that minimizes the value of SAD would *attempt* to select $\alpha^* = \alpha°$ as the optimal angle. ■

Although, in theory, one can determine an exact value of α that results in SAD being zero (in the planar case), the algorithm outputs only discrete values of α^*. Consequently, in practice, even for planar logs it is possible that $\min_\alpha\{SAD\} \neq 0$. Below are two examples of planar logs and an example of a non-planar log. The resulting output by implementing the algorithm is also provided. The center points are represented in a coordinate system wherein the x-axis is horizontal, the y-axis is vertical, and the positive z-axis is directed into the plane of the paper.

Planar Example 1.—Consider the slice centers given by the coordinates (2,2,1), (2,2,2), (3,3,3), (2,2,4), and (3,3,5), where the pivot point for the rotation is the second slice center (2,2,2). Note that the equation of the plane $\mathcal{P}$ may be represented as $x = y$. Hence the optimal rotation is clearly 45°, counterclockwise. For this initial position, $SAD = 2$. By using $\alpha = 45°$ in Eqs. (7) and (8), it is easy to see that the original points have been rotated to the points (2,2,1), (2,2,1), (2,3.4,3), (2,2,4), and (2,3.4,5), respectively. Now, $SAD = 0$ and hence $\alpha^* = 45°$ (counterclockwise). In this case, the rotated slice centers lie on the plane $x = 2$.

Planar Example 2.— Next consider the slice centers given by the points (3,1,1), (2,2,2), (1,3,3), (2,2,4), and (3,1,5); again, the pivot point for the rotation is the second slice center (2,2,2). Note that the plane $\mathcal{P}$ in this case is given by the equation $x + y = 4$. Hence the algorithm would yield $\alpha^* = 45°$ clockwise (or equivalently, 135° counterclockwise). In this case, the rotated slice centers lie on the plane $x = 2$.

Non-Planar Example.— It is safe to assume that real logs are non-planar. Thus, in light of the observation at the beginning of this section, it follows that the algorithm cannot reduce SAD to zero. As an example of a non-planar log, consider the log segment determined by the following slice centers: (4,4,1), (4,4,2), (5,5,3), (4,3,4), and (4,4,5). The original value of SAD is one. The algorithm determines that the minimum SAD is 0.71 obtained by rotating the log by an angle of 45° counterclockwise. The rotated log is still non-planar, but there has been some *straightening* of the log.

Next, we consider data obtained from eight real logs of the southern yellow pine species. The pivot point P_{piv} for rotation is chosen so that, x_{piv} is three feet into the log, or the 12th slice where slices are approximately three inches apart. Figure 2a and Fig. 2b show the projection of the the slice centers for each log on the xz plane (the dimensions of both axes are in inches). The *circles* indicate the original location of the slice centers, and the *squares* show the slice centers rotated by an angle α^* (in the xy plane), which minimizes the SAD. The horizontal line in the figures represents the centerline of the conveyor. In addition, Table 1 ("cw" stands for clockwise and "ccw" stands for counterclockwise) shows the percentage reduction in the SAD by rotating each log by an angle α^*. The percentage reduction in SAD is clearly a function of the scan data. If the log is in a *horns up* or *horns down* position initially, then one would expect the percentage reduction in SAD to be small. On the other hand, if the percentage reduction in SAD is large, then this indicates that prior to rotation by an angle α^*, the log was far from being in the *horns up* or *horns down* position. Consequently, a visual comparison of the log *before* and *after* rotation (see Fig. 2a and Fig. 2b), coupled with a record of the percentage reduction in SAD are good indicators of the effectiveness of the algorithm. For logs 2,3,4, (see Fig. 2a) and 6 (see Fig. 2b), the algorithm

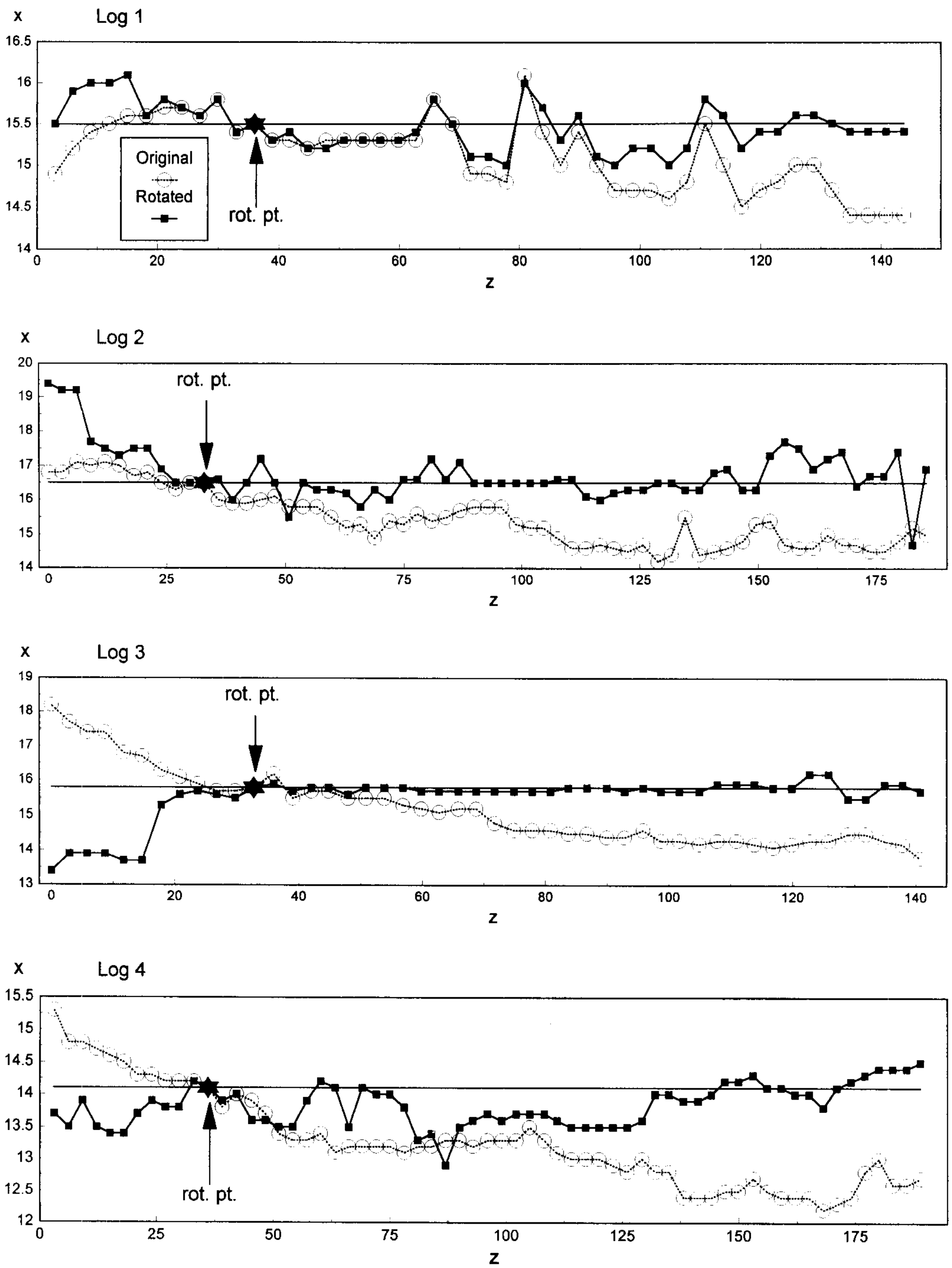

FIG. 2a. Original and rotated log profiles.

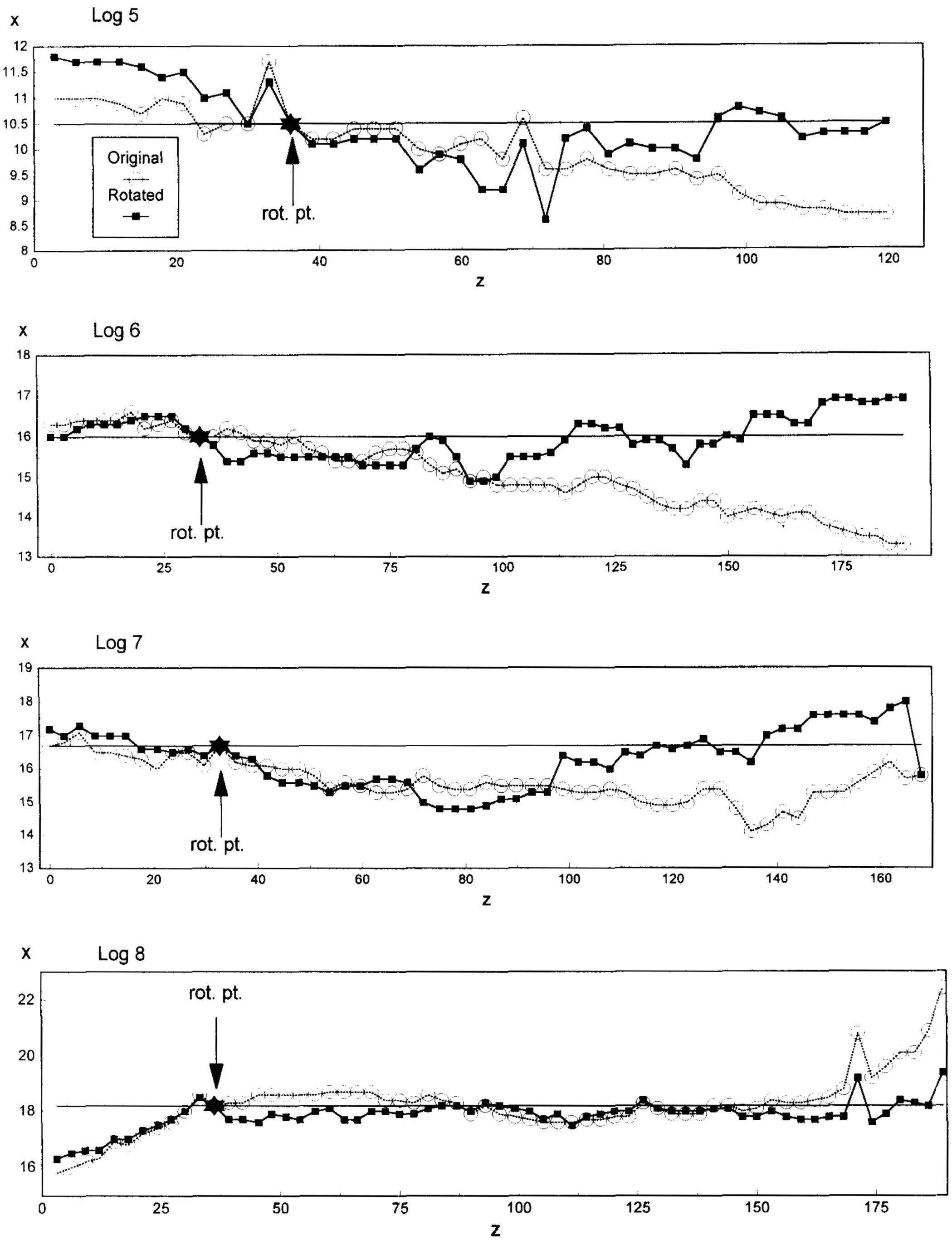

FIG. 2b. Original and rotated log profiles continued.

TABLE 1. *Percentage reduction in* SAD *under* α^*.

LOG	α^*	% Reduction in SAD
1	33°ccw	46
2	86°cw	57
3	80°cw	66
4	66°ccw	67
5	44°ccw	23
6	88°cw	56
7	58°ccw	31
8	29°ccw	39

tends to line up the center of the log with the axis of rotation and the percentage reduction in *SAD* ranges from 56% to 67%.

SUMMARY

It is well known that the southern yellow pine species have strong sweepy characteristics and consequently for straight sawing, rotating a log (if necessary) to the *horns up* or *horns down* position produces significantly higher yield. The simplicity, and consequently, the efficiency ($O(n)$) are two of the most salient features of the algorithm presented in this paper. Preliminary results indicate that the approach employed in this paper goes a long way in *straightening* a log from an arbitrary position on the conveyor to being *horns up* or *horns down*. It is our hope that by approaching the important problem of optimizing lumber yield in sawmills via elementary, yet, effective mathematical techniques, better results may be obtained. Regarding the specific problem of log orientation in the log breakdown process that we have considered in this paper, a more intricate approach involving multiple regression is being considered, also. We believe that further testing is required in order to determine exactly how effective this and other approaches are by correlating their performance with increased value recovery.

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