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Machine Vision Based Lumber Grain Measurement

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Abstract

In this paper, measurement of wood grains is discussed. A number of image processing techniques are first applied to images of all four long surfaces of sawn lumber. This gives us the rates and directions of the visible grains, which enables us to estimate the actual thickness and 3D directions of wood fibers. These are very important indicators about the strength of the subject.

In these experiments, we consider boards sawn from the heart side of the trunks of spruce trees. It is shown, how the position of the wood core can be estimated to few mm accuracy by only analyzing the grains seen on the surface. Also, we show how the measurements of fiber direction and density of annual growth correlate with the measured strength of the lumber.

1 Introduction

Traditionally, the lumber industry uses mechanical stress grading machines for bending lumber to assess its strength grade. These dynamic loading machines are slow and occasionally destructive. Recently, several alternative techniques have been developed for obtaining strength information without physical contact with the subject, using microwave scanning, x-ray or ultrasonic techniques [6, 11, 7], for example.

Fiber distortion constitutes the single largest strength-reducing factor of structural timber [4], as the breaking strength of wood can be more than 100 times in the longitudinal direction compared to tangential [3]. Fiber orientation can be assessed noncontactively using conventional vision, either in a direct manner, or indirectly based on knots.

The knots have a serious effect to fibers, and can thus be used as indirect indicators about the orientation. Dead knots are ones that are not attached to the surrounding wood, and are bypassed by nearby fibers. Sound knots are grown to surrounding wood and cause nearby fibers to rise up together with the knot, making the strength even worse.

On the surface boards, where large knots are present, knots are perhaps the single most important factor affecting to the fiber orientation and strength. Therefore, knots alone can be used to assess the strength and behavior of the lumber, for example by embedding these to a FEM model [4, 11]. There is a lot of research about locating and identifying knots using machine vision, see [8] for review, for example.

When the boards are sawn from the heart side of the trunk, the knots are typically small and many visible knots have an almost negligible effect on the strength, while fiber orientation remains important. As small as 5 degrees of grain angle deviation can result in 20% loss in strength [1]. Such a slope can occur due to sawing not parallel to bark or by greedy edging, but also exists naturally. Much greater deviations can be caused by the nearby knots, that might have even been cut out from the board by an edger system. These reasons suggest using direct measurement of fiber direction.

Elongated wood cells, tracheids, scatter light along their main orientation. This property is used by [9, 12], who use laser beams and cameras to determine the fiber orientation.

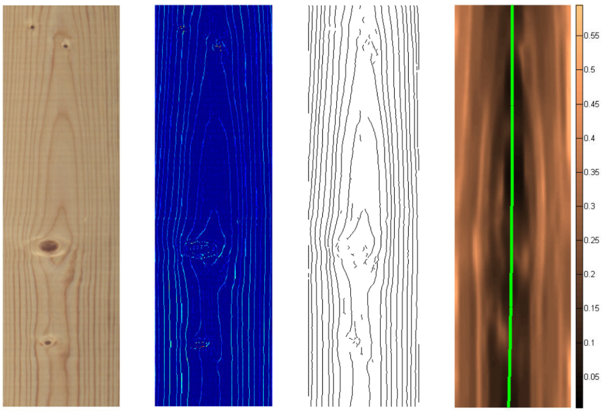
Seasonal growth of the wood results in grain patterns, which are often the only visible evidence of fiber distortion. Machine vision is rather cheap noncontactive method, and thus an attractive solution for measurements. Wood texture for making up a wooded panels is considered in [5]. A method for analyzing of oriented textures is proposed in [10]. The orientation fields were analyzed in order to get a description of the texture, and wood texture and its grain orientations were experimented with. Local texture descriptor LBP was used in [13] to define texture patterns of 64*64 pixels windows of sound wood. A classification based approach was then used to separate regions to six classes based on the grain orientation and scale.

In this paper, we focus on measurement of wood grains using conventional visible light camera. Measurements made from four long surfaces of the board give us a lot of information about the actual 3-D fiber structure that determines the dynamic strength. In Section 2, we present some image processing techniques to enhance the grains visible on the surface of the boards. It provides us the location of the heart of the trunk as will be discussed in Section 3. As a whole, this knowledge obtained informs us about the fiber stiffness and directions, both of which are very important when the lumber strength is considered (Section 4). Experiments (Section 5) show the accuracy of estimation of the core position, and relation between the bending strength and measured variables.

2 Direct Measurement of Grain Position

Measuring the visible grain positions on the surface of a lumber requires fast image processing. A board moves up to 10 meters per second while an image is acquired, and typically around 40Mpixels/s needs to be processed. Figure 1 (a) shows the piece of a board, where the image is already subjected to background thresholding, straightening and color correction.

Even after the color of the board is normalized, there might be substantial variation within one image, and the grains in the one part might be lighter than background elsewhere, preventing us from using simple thresholding. For softwood, late wood is still typically darker than the early wood surrounding it, suggesting using local approaches.



(a) (b) (c) (d)

Figure 1. Phases to form grain density map

The dynamic range of an original image is often too weak to separate the grains, while fast imaging leads to additional noise. Furthermore, a surface is often coved by dust and loose particles. For these reasons, we use line segment detectors [2] to compute gradient magnitude and orientation for the image. The detector is based on filtering with two special purpose masks that are designed to be maximally sensitive to typical grain width. Figure 1 (b) shows the magnitude of gradient obtained.

Next we segment the local maxima from the gradient image, based on segmentation obtained using a method closely related to well known Canny edge detector. First, all but local maxima are removed along the gradient direction. Two thresholds are determined, based on approximate knowledge about the average ratio between early and late wood. Gradient pixels exceeding the larger threshold will remain, as well as those that exceed the smaller one and are attached to the former. Very short segments are then deleted, resulting in the image where the grains (centers of visible parts of late wood layers) are segmented, as shown in Figure 1 (c).

For further analysis, we are interested in grain density everywhere in the lumber image. Several image processing techniques are applied to the segmented grain image. First, it is subjected to a distance transform, for which only vertically local maxima are preserved. The result contains values corresponding to distance between the adjacent grains. After filling the empty regions and median filtering a grain density map is obtained, shown in the Figure 1 (d). The amount of annual layers varies only slowly in longitudinal direction. Knots and dirt have only a minor effect on the grain density map obtained. In the figure, the scale shown is the number of the grains per mm.

The grain density map is later utilized to analyze fiber thickness and core position which is drawn on Figure 1 (d) based on approach presented in the next Section 3. A line segment detector also provides the gradient orientation, enabling us to access to grain slope. Less sensitive filters might be used for this purpose in order to avoid the possible confusions caused by the fallacious grain detections.

3 Core Position

The location of the board with respect to the core in the trunk provides important strength related information as it helps to infer the actual 3D fiber orientations from the visible 2D grain directions, and enables computing the grain deviation and density used in strength grading. With juvenile wood or typically stronger mature wood this might be the only cue available. Also, when building the exterior cladding out of wood, the side of the core needs to be known for each board.

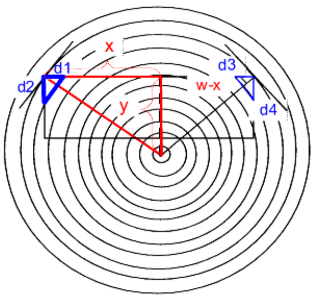
The principle of estimating the core position after 2-D grain measurements are obtained is shown in Figure 2 (a), where we wish to determine the position x and y. Unfortunately, we do not have the image from the end of the board. Instead, we note that the triangle formed by the x and y has the same shape with the one formed by the $d2$ and $d1$. Thus, we can write $x/y = d2/d1$, where $d1$ and $d2$ are the visible grain distances on the connected edges of the surface and side of the lumber board, and can be obtained from the grain density map. Similarly, a triangle formed by the distances $d4$ and $d3$ have the same shape with $(w - x)$ and y, where w is the width of the lumber board. This results in an equation pair

$$x = \frac{d2 \cdot d3}{d1 \cdot d4 + d2 \cdot d3}, \quad y = \frac{d1}{d2} \cdot x, \tag{1}$$

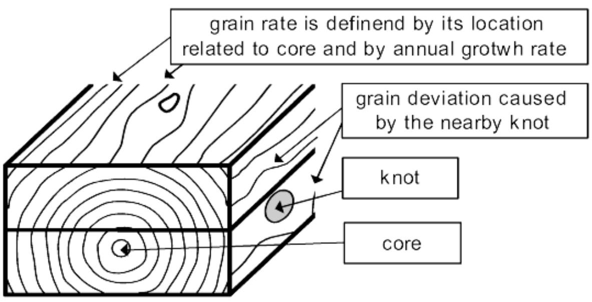
as shown in Figure 2 (a), given that we know the side of the core stripe.

Reasoning about the core side can equally be seen from the Figure 2. The observation is that the heart side of the board has much denser visible grains than the surface side, especially in the areas that are vertically close to the core. In the experiments, we simply computed the average grain density on the middle half at both of the flat surfaces of the board. The assumption is that the side with denser grains is closer to the core stripe. Other approach is to examine the sides only. For these, the visible grains should be denser further from the core, while the density should be zero when surface normal points toward it.

These simple reasonings gives us the core position with reasonably good accuracy, without the need for exact grain locations or correspondences. Of course, the wood is a natural material and Figure 2 (a) is simplistic. In reality, annual rings are not exactly round, and the core is not completely straight and its relative position may vary along the board.



(a)



(b)

Figure 2. Ideal (a) and real (b) situation to measure the fiber orientation

4 Grains and Strength

The variation of annual ring density causes variation to wood stiffness. For soft wood, the width of the late wood is almost constant, while the amount of early wood varies. Late wood is harder than early wood, and for this reason, more annual rings means stiffer wood. Utilizing the core position, the width of the annual rings can be computed location wise. However, even counting the number of visible grains as such is a good indicator about the strength. In the experiments, we found only a small difference between these alternatives, as each board is sawn approximately from the same position of the trunk.

Fiber distortion constitutes the single largest strength-reducing factor of structural timber. Using the visible 2-D grain directions and core position, 3-D orientation can be estimated, but a unique solution is hard or impossible to obtain. Still, the grain slope gives a lot of important information. It can, for example, reveal nearby knots that are cut out, as shown in Figure 2 (b) for upper board.

The experiments confirm that the most useful information about the visible grain distortion is obtained from the edges of the lumber surfaces. This comes from the two facts. Firstly, the visible grain change might differ a lot from the actual 3-D change, if the normal of the board surface points toward a core. In that case, the annual growth is tangential to the surface, and even a small change in radial direction can lead to clearly visible change in 2D projection of this layer. This property can be easily observed by looking the Figures 1 and 2. Secondly, the fibers divert the tension among the lumber. On the edges, if they point out from the piece, this results in a substantial decrease in capability to prevent bending. For these reasons we only consider the visible grain directions on the edges of the each four surfaces of sawn lumber.

5 Experiments

We have experimented with 96 pine boards, sawn from the heart of the trunk. The typical board size was about 1500mm*95mm*41mm and each piece was first imaged from all four long surfaces at about 0.5mm imaging resolution using a color line-scan camera. The boards were afterward subjected to destructive bending test to obtain the ground truth for strength estimation.

The core position for each board was manually measured from both ends of the boards, and the average value obtained was used. The measurement results vary from 10mm to 100mm in x and from -25 mm to 62 mm in y. Although used as ground truth, the measurements are not exact as the heart was often sawn about ten millimeters out from the board.

We compared the approach presented in the previous section to model based approach. It used a gradient based method in order to match the model of annual rings to grain density maps of four surfaces. The first experiment was to evaluate the side of the core, simply saying which of the two flat surfaces the core is closer to. Both approaches, one that uses only flat surfaces and the other that uses only sides as described in Section 3, were compared to the model fitting based approach. The results are shown in the Table 1.

Table 1. Prediction of core side

	Flat surfaces	Sides	Model
Accuracy	96.8%	97.8%	96.8%

The difference between the approaches is insignificant. Two of them misclassified three and one misinterpreted two boards out of 96. The result is good, showing that the grain detection method works as desired. Also, the method produces much better results compared to typical 80% accuracy achieved by industrial systems designed for the purpose.

The table 2 shows both the average and median errors, when core position was assessed using model fitting and intersection method presented in the Section 3. Median error is a better indicator in the sense that it is not affected by incorrect detection of core side. However, the mean error indicates more about the robustness. Local minimization based model fitting often results in a slightly better accuracy than simple intersection method, however, it can be eventually attracted by wrong minima, and result in a substantial error as indicated by the poor average result.

Table 2. Prediction error for core (mm)

	x avg.	x median	y avg.	y median
Intersection	5.22	4.12	4.28	3.42
Model fitting	10.95	3.30	16.62	3.13

It should be noted, that in reality the core does not necessarily point directly upwards. Also, it is not necessarily straight, but the position can change around 1 cm even at a few cm distance. Thus, the average position is not always the same as that which can be measured from the ends.

The final test compared the relation between the measurements and actual strength. A coefficient of determination (r^2) is used to tell us how well these correlate. Table 3 shows the values between annual ring width (model based), grain deviation and grain density (2D cues), and breaking strength and modulus of elasticity (MOE). Also, the first two 2D cues were combined.

Table 3. Strength correlation with grains

	Breaking strength	MOE
Ring width	0.35	0.31
Grain deviation	0.26	0.30
Grain density	0.33	0.28
Two previous combined	0.38	0.37

It should be mentioned, that for this material other visual cues are practically useless. Dimension is almost equal and there are only a few shakes in the material. The knot based features seem to be very poor indicators giving almost no information at all for this particular test set.

6 Conclusions

Measuring wood grains using machine vision was considered. A number of image preprocessing steps were performed in order to obtain grain density around the lumber surface.

Grain directions and densities were obtained with good accuracy. Also, we were able to find the position of core stripe with < 0.5 cm agreement with a human. Finally, correlation between wood grain based measurements and its strength were assessed.

To obtain better correlation with breaking strength, grain directions should probably be embedded into a FEM model, that simulates the actual bending process more accurately. However, we are well aware of its huge demands in computation power. The proposed fast grain measurement approach can be alternatively embedded in a training based lumber classification system, for example.

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