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Determination of wood grain direction from laser light scattering pattern

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Abstract

Laser light scattering patterns from the grains of wood are investigated in detail to gain information about the characteristics of scattering patterns related to the direction of the grains. For this purpose, wood samples of Scots pine (*Pinus sylvestris* L.) and silver birch (*Betula pubescens*) were investigated. The orientation and shape of the scattering pattern of laser light in wood was found to correlate well with the direction of grain angles in a three-dimensional domain. The proposed method was also experimentally verified.

Keywords: Laser light scattering; Wood grain direction; Diving angle

1. Introduction

Wood is an anisotropic material and the wood tissue itself is composed of hollow and spindle-shaped elongated cells called tracheids. The slenderness ratio of the softwood tracheids is about 100 and their direction determines the grain direction of the wood tissue. Almost all the mechanical characteristics of wood depend on the grain direction, i.e. strength, toughness and elasticity [1]. In lumber industry the sawing of a log is often done with precision along the grain in order to obtain best possible strength and form stability. The grain direction of wood is usually parallel to the longitudinal direction of the stem. Slight deviations, caused by external forces

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and environmental factors, may occur [2,3]. The effect of wind and crown development are some of the reasons causing a phenomenon known as spiral grain. Natural deviations, such as knots or clusters of knots, which are often referred as defects of wood in the lumber industry.

Measuring the grain direction on logs and sawn timber is difficult. Using sharp stylus is one method, but it is only capable of measuring the orientation on the surface. A non-destructive method for measuring the grain direction is based on measuring the dielectric constant of wood. This technique uses a rotating capacitance head and it is known as the capacitance technique [4]. The apparatus needed for this technique is a complex and the method is rather sensitive to variations in moisture content in the sample [5]. Thus, a new method for grain direction determination of wood is needed. A laser light has been applied to the inspection of both macro- and microstructures of wood tissue and their influence in wood density [6], microcracks [7] and orientation of microfibres [8].

In this work, we introduce a new optical method to determine the grain direction of wood from laser light generated scattering pattern on the surface of wood. We observed the correlation between the characteristics of the scattering pattern and the grain direction angles in a three-dimensional domain. The orientation and shape of the scattering pattern are shown to depend on the grain direction. The new method for determination of grain direction is also experimentally tested and verified to be effective.

2. Scattering pattern

The scattering pattern is generated on the surface of wood when laser light scatters from the composite structure of wood tissue. Let us consider the factors that affect the characteristics of the scattering pattern on the wood surface. First, we have to define how to affix the coordinates of the system in the chosen surface plane under investigation. This is shown in Fig. 1. If we examine the radial surface plane, which is denoted by the letter B and is shown in the Fig. 1(a), the deviations in grain direction can occur on that plane as well as off that plane. As illustrated in Fig. 1(b), the surface plane is affixed to the xy-plane and the grain direction is denoted by a vector G. The angle of deviation on the surface plane is called grain orientation angle α and it is the angle between the projection of grain direction vector G in xy-plane and x-axis. The angle between the grain direction and its projection in the xy-plane is called diving angle β. Since, here we assume that the incidence angle of the laser light is zero, the laser light wavefront propagates in the direction of the positive z-axis. Note that the xy-plane is affixed to the surface plane. So, that the grain direction value β is related to the inspected surface plane, not to any specific direction in wood, whereas the grain direction value α depends on how we affix the x-axis, which is the reference direction for the orientation. The same is valid for the transverse, tangential or any other random surface plane where the grain direction is examined.

When incident light propagates in a longitudinal direction perpendicular to the transverse plane, and the observation of the scattering pattern occurs in the direction

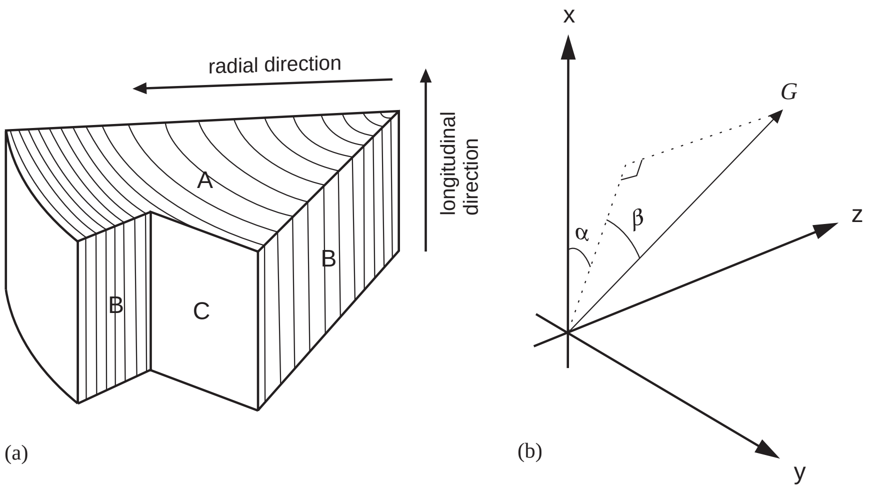

Fig. 1. (a) A, B and C are transverse, radial and tangential (surface) planes, respectively, and (b) the grain direction angles: the grain orientation angle α and the diving angle β. Note, that the xy-plane is affixed to the surface plane under investigation.

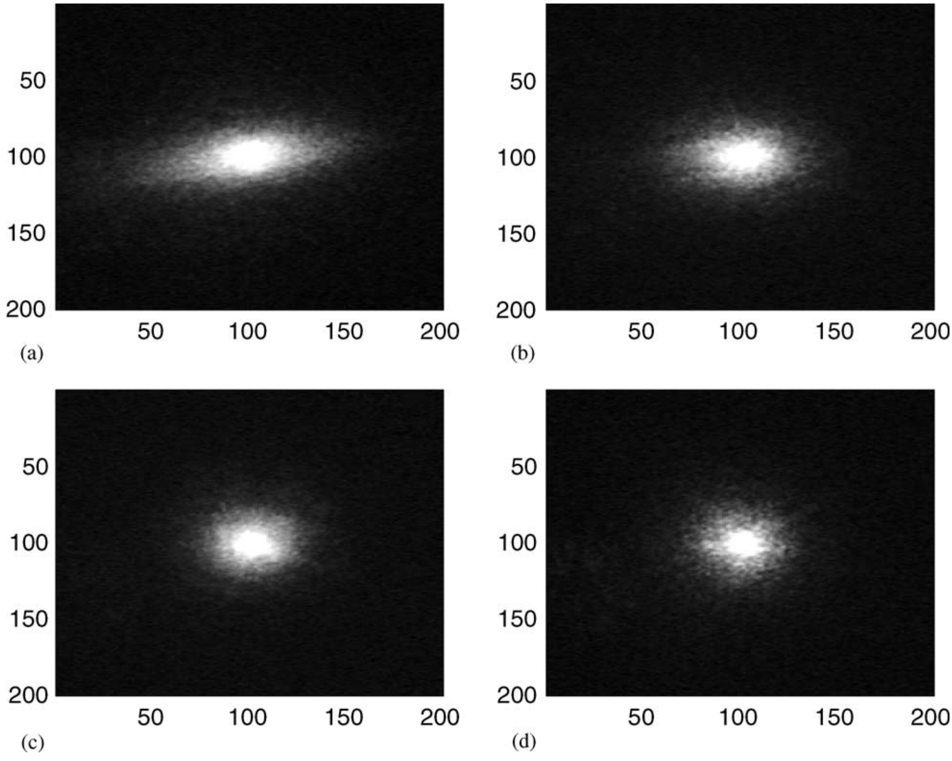

Fig. 2. Scattering patterns observed on the wood surface with diving angle: (a) $\beta = 0^\circ$; (b) $\beta = 30^\circ$; (c) $\beta = 60^\circ$; and (d) $\beta = 90^\circ$. Note the slight deviation in the orientation angle α in Fig. 2(a).

of specular reflection, the scattering pattern is almost circular. In a radial or tangential plane the scattering pattern of incident light takes the shape of an oval pattern. The reason for this is the fact that the cell walls and cell cavities act as optical waveguides, which stretch the scattering pattern observed on the surface of the sample into the grain direction [6]. Thus, the orientation of the scattering pattern on the surface of the wood is related to the orientation of the wood grains, and specifically only to the angle α shown in Fig. 1(b).

In a case where the deviation of grain direction occurs off the surface plane, the diving angle β differs from zero. Since the scattering increases in the direction of the grain, the increase in β shortens the major axis of oval scattering pattern observed on the surface plane. In an extreme case where the grain direction is perpendicular to the surface plane, the scattering pattern is reduced to a more circular shape. This implies that the diving angle β is strongly related to the shape of the scattering pattern. An example of this behaviour is shown in Figs. 2(a)–(d), where the images of the scattering patterns are obtained with the method explained in the next chapter.

3. Materials and methods

We prepared two sample sets for the experimental determination of the diving angle β. One set consisted of samples from Scots pine (*Pinus sylvestris* L.), and the other from silver birch (*Betula pubescens*). Each sample was prepared from the wood with a minimum amount of deviations in grain direction from longitudinal direction. The samples were sawn so that the diving angle β on the sawing plane varied from 0 to 90° at intervals of 10° in both sets (Fig. 3). It should also be noted that the angle of grain orientation α on the surface plane of all samples is now zero.

The measuring setup shown in Fig. 3 consisted of a He–Ne laser, a charge-coupled device (CCD) camera and a motorized sample holder. The He–Ne laser ($\lambda =$ 632.8 nm) was chosen due to a negligible transmittance at wavelengths lower than 600 nm as seen in the Fig. 4. The use of a wavelength over 600 nm provides a stronger scattering of light inside the wood and thus increases the effect of the grain direction on the scattering pattern. The wood samples were illuminated with a linearly polarized He–Ne laser beam with an angle of incidence of zero. The diameter of the incident beam waist on the surface of the sample was approximately 1 mm at $1/e^2$-level of intensity. The motorized sample holder moved the sample in a plane perpendicular to the incident beam, while the scattering pattern on the surface of the sample was captured by the CCD camera. The captured images were analysed using a PC.

The analysis of the images was divided into two tasks. The first task was to determine the orientation of the scattering pattern from the images taken by the CCD camera. For this purpose, we used a statistical method called principal component analysis (PCA) in the calculations [9]. The second task was to determine the connection between the shape of the scattering pattern and the diving angle β. Since the shape is an oval, we applied the use of shape factor R [10], which is the ratio of the minor-to-major axes of the oval.

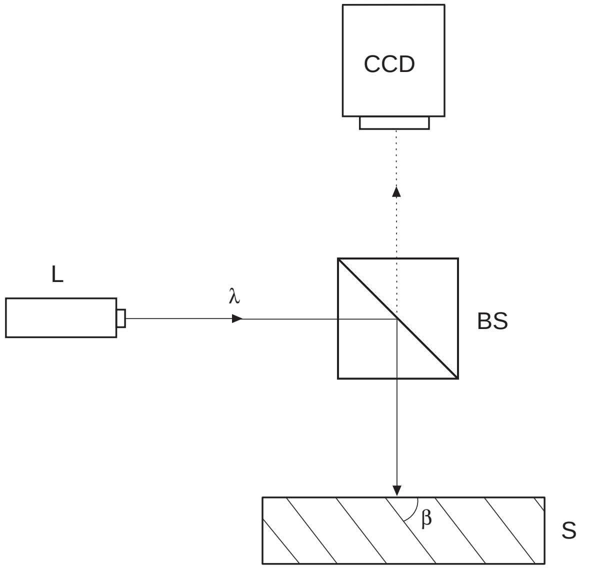

Fig. 3. The measuring set-up for optical detection of the grain direction. The wavefront λ of a laser (L) is guided by a beam splitter (BS) into a wood sample (S). The CCD-camera captures the reflected scattering pattern.

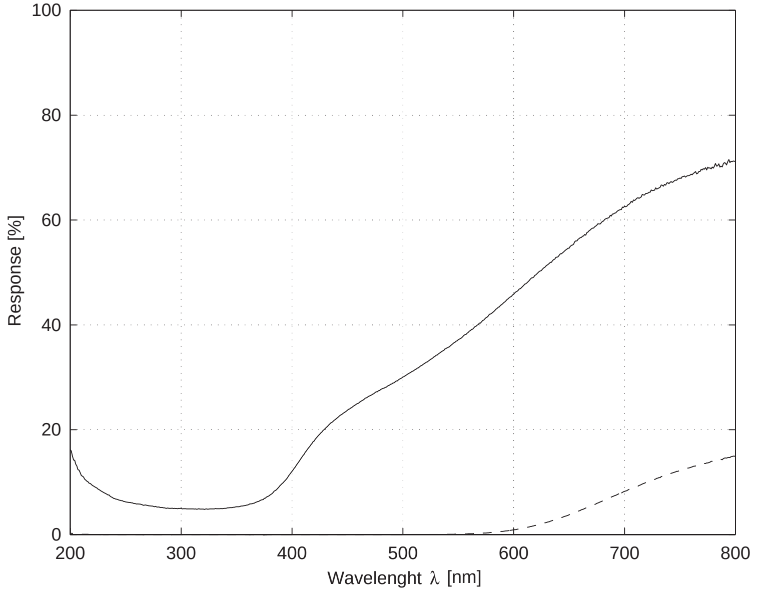

Fig. 4. The spectral transmittance (dashed line) and reflectance (solid line) of a 3 mm thick wooden sample measured by Perkin-Elmer λ18 spectrophotometer as a function of wavelength λ.

4. Results

We evaluated the accuracy of the grain orientation measurement method by rotating a wood sample 90° at intervals of 1° in a clockwise and counterclockwise direction while measuring the grain orientation as a function of the rotation angle θ. Only some insignificant fluctuation in the grain orientation exist, as observed in Fig. 5. The standard deviation is less than 0.29° and the squared Pearson's product–moment correlation between the grain orientation and the angle of rotation yields a value $r^2 = 0.99997$.

The next step was to find out the relation between the shape of the scattering pattern and the diving angle β for sample sets of Scots pine and silver birch. For each sample, the measurement was performed at an area of $5 \times 5\,\mathrm{mm}^2$ with 1 mm intervals. Thus, the total number of measurements for each diving angle was 36. The mean value of the shape factor R and the standard deviation ΔR was calculated for each sample as a function of β. The results are shown in Fig. 6. We can easily see that the measured values of the shape factor for both sample sets are nearly the same. The magnitude of the standard deviations can be explained by the anisotrophy of the wood structure in the overall area of the measurement. These include, e.g. difference between early and latewood tracheids, occurrence of pits, resin canals and compression wood [11]. Since no significant difference between the mean R-values of pine and birch sets exists, in further analysis they are treated as values of one combined set. Finally, we fitted a function to the measured data. This is shown in the Fig. 6. With the inversion of this experimentally obtained

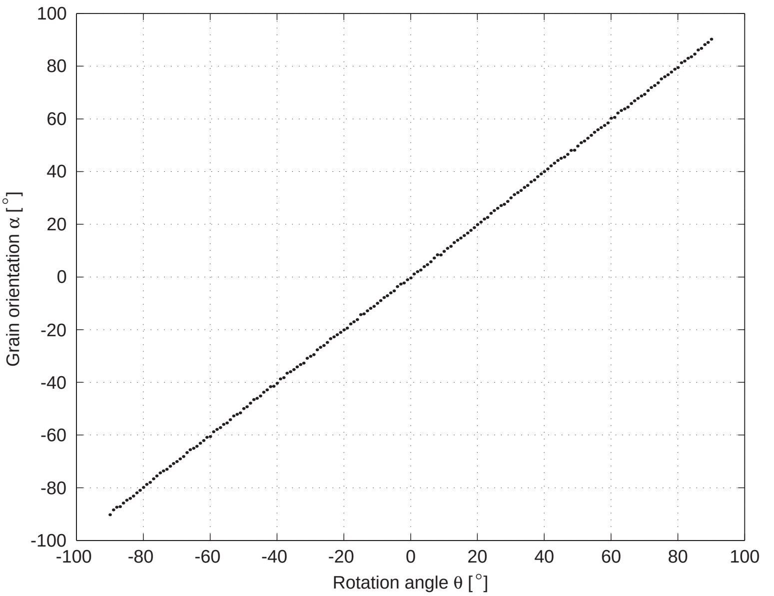

Fig. 5. The measured grain orientation angle α as a function of rotation angle θ from a Scots pine sample.

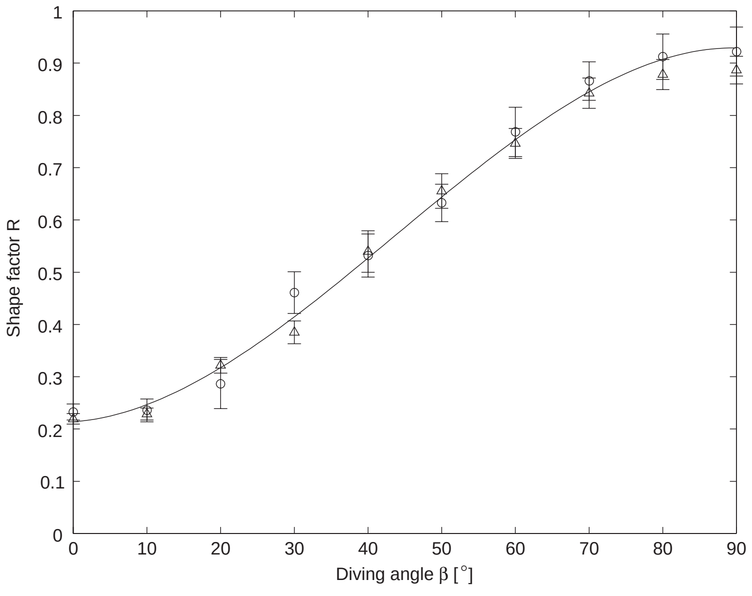

Fig. 6. The measured shape factor R as a function of diving angle β for pine (open circles) and birch (triangle). The vertical lines denote the standard deviations. A fitted function for the R values of combined set of pine and birch is represented with solid line.

function, we have a method to calculate the diving angle β from the measured shape factor R.

Evaluation of the accuracy of the diving angle measurement method was performed by a set of measurements as follows: First, we chose a knotted wood sample, since knots cause great deviations in the grain direction of wood. One may observe from Fig. 7 that approximately one-third of both measurement areas of the sample, represented by the dotted lines, are affected by the knot. The diving angle β on the tangential surface was measured using the shape factor R and the grain direction (angle α) on the radial surface was measured using the grain orientation method, as already explained. These measurements were performed near the intersection of these surfaces for a distance of 100 mm at intervals of 2 mm as seen in Fig. 7. Since the accuracy of the grain orientation method has already been verified, in this case we may assume that the β values on the tangential surface is equal to the α values on the radial surface. After one measurement from both surfaces, we removed a 0.5 mm thick slice from the radial surface with an electrical hand plane and repeated the measurements. This was performed a total 24 times. We rejected values acquired from the heavily cracked area in the middle of the knot, since the scattering pattern was noticeably distorted and did not give correct results. This was possible to detect under visual inspection during the measurements. By comparing the measured values of α on radial surface and values of β on tangential surface, we may evaluate the quality of the diving angle measurement method. The respective

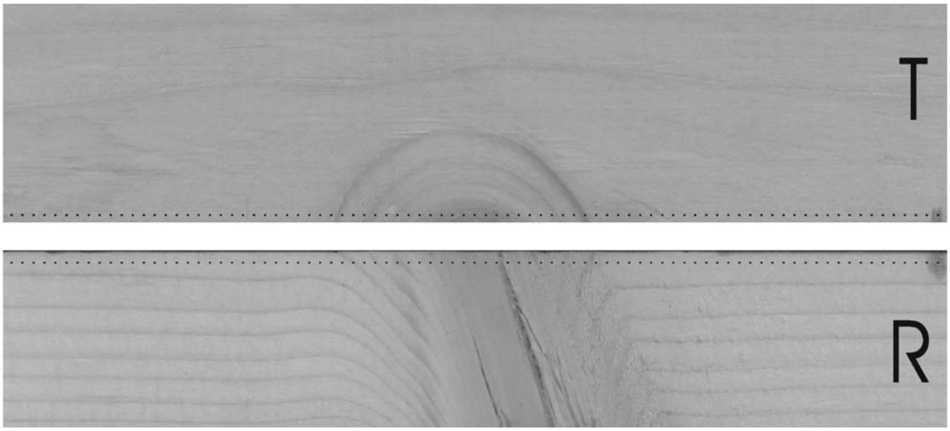

Fig. 7. Measurement points (dots) on tangential (T) and radial (R) surface near the intersection of these planes for a Scots pine wood sample.

correlation yields a value $r^2 = 0.9109$. This shows that even in the near proximity of the knot the diving angle measurement method is very accurate. However, if the wood surface has a lot of defects such as cracks, the accuracy of the measurement method can be expected to decrease.

Surface roughness has its own effect on the optical scattering in wood [12] and, thus on the accuracy of the grain direction measurement method. We also observed that even a very light sandpapering disturbed the scattering effect, apparently due to sanding dust filling the lumens of the wood cells. Consequently, in future research we will focus our interest on investigating the effect of different surface roughnesses on the accuracy of our grain direction measurement method. This report deals with efficiency of the method for wood samples of two species, Scots pine and silver birch, with same surface roughness. The applicability of the current method for wood species different from those reported here will also be one of our primary areas of interest.

5. Conclusions

A method based on the analysis of characteristics of the laser generated scattering pattern, namely the orientation and shape of an oval pattern, was developed to define the three-dimensional grain direction of wood. Furthermore, with this method it is possible to determine both the grain orientation on the wood surface, and the diving angle of the grain at the same time. The accuracy of experimentally obtained function for the relation of shape factor and diving angle was verified. The respective correlation yielded a value of $r^2 = 0.9109$, which proves the method to be effective. Since the method itself is simple, it is also practical.

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