Directional variance analysis of annual rings

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Abstract. The wood quality measurement methods are of increasing importance in the wood industry. The goal is to produce more high quality products with higher marketing value than is produced today. One of the key factors for increasing the market value is to provide better measurements for increased information to support the decisions made later in the product chain. Strength and stiffness are important properties of the wood. They are related to mean annual ring width and its deviation. These indicators can be estimated from images taken from the log ends by two-dimensional power spectrum analysis. The spectrum analysis has been used successfully for images of pine. However, the annual rings in birch, for example are less distinguishable and the basic spectrum analysis method does not give reliable results. A novel method for local log end variance analysis based on Radon-transform is proposed. The directions and the positions of the annual rings can be estimated from local minimum and maximum variance estimates. Applying the spectrum analysis on the maximum local variance estimate instead of the original image produces more reliable estimate of the annual ring width. The proposed method is not limited to log end analysis only. It is usable in other two-dimensional random signal and texture analysis tasks.

1. Introduction
The measurement of the annual ring width of log ends gives valuable information about the wood quality, especially strength and stiffness. The mean and standard deviation of the annual ring width is measured from a digital image taken from the log end. This data can be used for example when estimating the strength and the stiffness of the log [4]. When data about annual ring width is combined with the information about log end shape, shape of the trunk, side images and location of centre of the annual rings, it supports deciding whether the log is more suitable for plywood, paper or plank making so that wood is used more cost effectively and the quality of the wood based products is improved.

The mean and standard deviation of the annual rings can be estimated from the digital images using 2-D power spectrum density (PSD) [5]. The 2-D PSD provides the mean annual ring width and the direction normal to the annual rings as the maximum variance estimate. The PSD analysis gives reliable estimates for example pine (Pinus sylvestris), where the individual annual rings are clearly visible. However, PSD method fails on woods that have less distinguishable annual rings, birch (Betula pubescens) for example. The annual ring width estimate can be improved by utilizing Radon transform as intermediate step.

The two-dimensional (2-D) Radon transform is usually used in problems where measurements are projections and the three-dimensional shape of the object has to be reconstructed such as [2] and [3]. The 2-D Radon transform is somewhat used in the texture analysis also as in [1], [7] or [8]. The 2-D Radon transform can be used for two-dimensional spectrum estimation [9]. The directional moment
analysis of the global or local image areas can also be performed. This paper focuses on the local analysis of the log end variance as a function of position and angle. The variance estimates are used for detecting the minimum variance direction of the local region. The direction of the minimum should correspond to the tangent of the annual rings. The direction of the maximum local variance should correspond to the radius of the log, orthogonal to the direction of the minimum. The position of the annual rings can also be detected using the positions of the local minima. PSD analysis applied on the maximum local directional variance produces improved estimates of the annual ring width.

In this paper we introduce examples of the annual ring width estimates of pine and birch logs. The PSD analysis gives usable results of the pine log but fails with the birch log. We then use the Radon transform to provide local directional maximum variance as input to the PSD analysis. This enables the PSD analysis to give usable annual ring width estimates of the birch log too. The result is compared to a manual measurement made of the original image.

2. Power spectral Analysis

The annual ring width is computed from the digital image using 2-D Fourier spectral analysis [5]. The 2-D \( \text{psd} \) describes the variance of the image after removal of the mean and the trend [10]. The Fourier transform represents the signal as a sum of sinusoids and is defined as

\[
F(u, v) = \Phi(m, m)f(p, p)\Phi(n, n)
\]

Here \( \Phi(m, m) \) and \( \Phi(n, n) \) are the forward transformation kernels. The power spectrum is the squared absolute value of the Fourier transform. The original signal (image) is often windowed before the Fourier transform. The use of an attenuating window reduces the amount of so called spectral leakage.

The annual rings can be seen as periodical or nearly periodical structures when the computation window size is well selected. These periodical signals are shown as peaks in the power spectrum and the annual ring width and direction computation is turned into a peak search. The peak search is a maximum search after removal of the DC induced peak at \((0, 0)\) frequency. The spectrum has a discrete frequency resolution. The maximum search produces a result that is directly related to the frequency resolution of the spectrum. Therefore a polynomial fit is done to the maximum and its close neighborhood [5]. The maximum of the fitted function is used as the new interpolated value for the peak position \((u_0, v_0)\).

The radial frequency describing the frequency of the dominant annual ring is computed as \( f_r = (u_0^2 + v_0^2)^{1/2} \). The estimated annual ring width is the inverse of the radial frequency

\[
\lambda = \frac{1}{f_r}
\]

The direction normal to the annual rings is computed as

\[
\theta = \arctan\left(\frac{v_0}{u_0}\right)
\]

The analysis can be performed as a function of position producing a two-dimensional measurement of the annual ring widths and directions.

3. Radon transform

The Radon transform is an integral transform consisting of integral of two-dimensional continuous function over straight lines. The measured two-dimensional images require a discrete approximation of the continuous Radon transform [6]
\[ R(\tau, p) = \sum_l \sum_j u(j\Delta t, l\Delta x) \text{sinc} \left( \frac{l'}{\Delta t} - j \right) \]  

(4)

Where \( \text{sinc}(x) = \sin(\pi x)/\pi x \). This interpolation part of the discrete radon transform may vary.

The variance and mean estimates of two-dimensional data can be expressed as sums divided by the number of elements used in the estimation. The discrete Radon transform is essentially a summing operation and the local variance can be estimated as difference between mean of squared data and the squared mean of data [10]

\[ \sigma^2(\tau, p) = \psi^2(\tau, p) - \mu(\tau, p)^2 \]

(5)

The mean of squared data from Radon transform is defined as

\[ \psi^2(\tau, p) = \frac{\sum_l \sum_j u(j\Delta t, l\Delta x)^2 \text{sinc} \left( \frac{l'}{\Delta t} - j \right)}{N(\tau, p)} \]

(6)

The mean of the data is defined as

\[ \mu(\tau, p) = \frac{\frac{1}{N} \sum_l \sum_j u(j\Delta t, l\Delta x) \text{sinc} \left( \frac{l'}{\Delta t} - j \right)}{N(\tau, p)} \]

(7)

The normalization variable \( N(\tau, p) \) can be obtained analytically or from equation (4) using a signal having only ones in the defined spatial domain. The estimation is most easily performed with transforming the spatial domain in the computation program.

The directional variance estimate contains the variance as the function of angle and slope. The total variance as the function of angle is the marginal function of the estimate as a function of \( p \). That is

\[ \sigma^2(\tau) = \sum_p \sigma^2(\tau, p) \]

(8)

The local variance estimates are obtained by using sliding windows and the results are returned as functions of window position. The results can be used to further analyze the properties of the data under study. In this paper we find the minimum and maximum variances as the function of direction.

4. Estimates of the annual ring width and orientation

The annual ring width and orientation are estimated from images of two log ends are used to provide an example of the methods. The first log end is a pine (\textit{Pinus sylvestris}) and second is a birch (\textit{Betula pubescens}). The images of the log ends are presented in figures 1 and 2. The annual rings of the pine are clearly visible. Contrast between the annual ring borders is lower in the image of the birch. That makes it difficult for the PSD analysis to estimate the annual rings. In this case the birch log is smaller and less symmetrical than the pine.
Figure 1. The pine used in the example.

Figure 2. The birch used in the example.

The PSD based estimate of the annual ring width of the pine is presented in figure 3. The result coincides with the original image in figure 1. There are narrow rings right around the centre and in the outer part near the surface. The thicker rings, depicting faster growth are located in between. The mean of the annual ring width is 3.2 mm, and standard deviation 1.5 mm.

Figure 3. The PSD based ring width estimate of the pine.

Figure 4. The PSD based ring orientation estimate of the pine.

The PSD produces a consistent estimate of the annual ring orientation of the pine as presented in figure 4. In this example there are only couple of points, where the estimate fails. They are shown as white spots of value π radians.

Direct PSD based estimates of the annual ring width and orientation for the birch are given in figures 5 and 6 respectively. The zero value of the ring width, represented by black in figure 5, means that the estimation failed. This includes the background outside the log as well as most of the area of
the log end. A valid estimate is produced only in a small part of the log. Thus it is obvious that the estimation by PSD fails in the majority of the log end area.

The same applies to the estimate of the orientation of the annual rings in figure 6. Zero value (medium gray) presents the areas where the estimation has failed.

**Figure 5.** The PSD based ring width estimate of the birch.

**Figure 6.** The PSD based ring orientation estimate of the birch.

The Radon transform is used to calculate the local directional variances for the birch using windows of 11 x 11 pixels. Figure 7 presents the direction of the minimum local variance. The estimate seems to be reasonable, excluding relatively small areas.

**Figure 7.** The direction of the local minimum variance of the birch, based on radon transform.

**Figure 8.** Local maximum standard deviation of the birch, based on radon transform.

The maximum local variance describes the variation of the intensity in the image. The maximum standard deviation (square root of the variance) of the birch is presented in figure 8. While the sliding
window smooths the image, the contrast of the annual rings is enhanced. The white border around the log is produced by the sharp edge of the wood against the background.

The maximum variance is used to estimate the annual ring width and orientation of the birch by PSD method. The estimate of the annual ring width is presented in figure 9. There are small areas where the estimation has failed but the most of the log end is covered by a valid estimate of the ring width.

![Figure 9. Annual ring width estimate of the birch. PSD applied on the local maximum variance from radon transform.](image)

![Figure 10. Annual ring orientation estimate of the birch. PSD applied on the local maximum variance from radon transform.](image)

The estimate of the orientation of the annual rings is given in figure 10. The result is mostly consistent with small areas of arbitrary values. The proportion of the failed parts is far less than in figure 6, where the PSD method was used directly on the original image.

The mean and standard deviation of the annual ring width are concise figures that describe the quality of the wood. These values are given in table 1. The results of manual measurement from the original image are presented on the first line. The following lines contain the results of the direct PSD method and the PSD calculated from the maximum local variance of the Radon transform. The areas where the estimation failed were ignored in both.

|                          | Mean width (mm) | Standard deviation (mm) |
|--------------------------|-----------------|-------------------------|
| Manual measurement       | 10.34           | 2.57                    |
| Direct PSD               | 3.00            | 0.75                    |
| Radon + PSD              | 11.27           | 3.10                    |

The results of the direct PSD method are obviously erroneous. Including the maximum variance from the Radon transform as intermediate step (or preprocessing) enables the PSD to estimate the annual ring width relatively accurately. However, it should be noted that it is sometimes very hard even for human expert to see the annual rings properly and to measure their widths.
5. Conclusion
Two log ends are used to estimate the annual ring width and orientation. The 2-D PSD method seems to work well for pine. For further analysis of the measurement uncertainty using 2-D PSD see [5]. The 2-D PSD analysis does not work properly for the birch. The annual rings are sparsely located and not very well distinguishable. The estimation fails in the major part of the log end and only small areas are estimated properly.

The 2-D Radon based minimum variance analysis gave reasonable estimates of the annual ring orientation for the birch. The local maximum variance used as an input for the PSD improved the estimates of the annual ring width of the birch. The orientation estimate also benefits from combining the Radon transform with the PSD based estimate.

This combination of methods seems promising in estimating the quality properties of birch, which has been a very challenging task. The future work includes testing the method with a larger set of images. The computation speed of the Radon transform in sliding windows can also be improved.

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