Evaluation anisotropy in stochastic texture images using wavelet transforms for characterizing printing, coating and paper structure.

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Abstract

A novel method for evaluating the anisotropy of the deterministic features in a stochastic 2D data is introduced. The ability of the wavelet transform for the identification of the abrupt discontinuities could be used to characterize the boundary of the deterministic area in a 2D stochastic data, such as flocs in paper structure. The one-dimensional wavelet transform with a small-scale range in MD and CD could quantify the amount of the edge in both directions, depending on the intensity of each floc. The flocs that are aligned in the MD direction result in a higher value of local wavelet energy in the CD direction. Therefore, the ratio of the total wavelet energy in CD and MD directions can be used as a new anisotropy index. This index is a measure of the floc-orientation and can provide an excellent tool to obtain the orientation distribution and the major oriented angle of flocs. Various simulated images and real stochastic data such as local gloss variation of printed image and formation image, have been tested and the results show this analysis method is very reliable to measure the anisotropy of the deterministic features.

Keywords: anisotropy, wavelet transform, floc-orientation, printed image, image analysis

1. Introduction

During papermaking processes, the paper web is subject to a mixture of hydrodynamic forces, especially shear forces, at the forming zone[1] and continuous tension in MD (machine direction) during pressing, drying and converting processes[2].

These effects could result in the stretching of the deterministic features toward MD and might lead to not only individual fiber orientation but also the floc-anisotropy in paper structure and surface[3]. Since the anisotropy has significant influences on the several end use properties, such as the optical properties, the mechanical properties[4], and the dimensional stability[5], many researches have been proposed several methods for evaluating the anisotropy accurately[6-8]. Most of those works have much focused on the individual fiber orientation rather than the anisotropy of flocs. Although, recently, the image analysis method using a gradient operator was introduced and applied to evaluate local anisotropy of flocs [9;10], more study on the orientation of flocs is greatly required to improve paper quality by adequate control of papermaking process. In this study, a simple method based on the wavelet analysis is developed applied to various simulated images and real paper samples.

2. Principle

2.1. The Wavelet Transform Analysis

Wavelet transform analysis is a method for analyzing localized variations by decomposing a data into space and scale component in which it becomes much easier to study interesting features of the original data or to describe the original data concisely[11]. The wavelet transform is a convolution of the wavelet function, localized waveform, Ψ, which satisfies certain mathematical criteria, with a data.

The wavelet function can be manipulated through dilation and translation. The family of the wavelet function is given by

$$\Psi_{a,b}(x) = |a|^{-1/2}\,\Psi\left(\frac{x-b}{a}\right)$$, where a = scale of mother wavelet, b = positions. (1)

Since the mother wavelet or basis wavelet, Ψ, play very important role in the wavelet analysis, the specific application of the wavelet analysis must be considered before the selection of the mother wavelet. As pointed by Keller[12], the second order Gaussian functions is useful to distinguish the variation of various features depending on the scale, e.g. flocs, streaks, or several defects, were used in this study. The second order Gaussi an function is also called as "Mexican Hat" or "Marr Wavelet" and the equation of the wavelet function is given by;

$$\Psi_{G^2}(x) = (x^2 - 1)e^{-x^2/2} \qquad (2)$$

The convolution of one dimensional data set with this second order Gaussian wavelet results in a two dimensional set of wavelet coefficients indicating the scale and position of various wavelet spectral density. In case of the second order Gaussian wavelet, the scale can be converted to wavelength, which is equivalent with the Fourier Wavelength, λ, as given by;

$$\lambda = \frac{2\pi a}{\sqrt{2.5}} \qquad (3)$$

Therefore, the scale dependence nature of the stochastic data can be easily interpreted and the detailed information of specific spatial range can be easily isolated.

2.2. Edge detection and Anisotropy Index

The wavelet transform has a useful property that the ability to detect abrupt discontinuities ('edge') in the data. If the scale of the basic wavelet is fixed as a small range, the wavelet energy is affected only by small-scale changes in data, which indicates the boundaries of flocs. If we use the larger range of wavelet transform scale, the wavelet transform detect not only the edges but also the small size of flocs, which could reduce the accuracy of this analysis and lead to miss interpretation. Therefore, the determination of the edge within the data set is very important and can be changed depending on the data. We choose the spatial wavelength of the 2 ~ 4 pixels in this study as the boundaries of flocs.

Figure 1 illustrates the edge detection by the wavelet transform. A line profile of the simulated data image shows the edges of the flocs with various size and intensity. The wavelet analysis identifies the edges and indicates the position and the intensity of those as local wavelet energy. The higher local wavelet energy represents the bigger variation in image, which are originated from various intensities of the flocs.

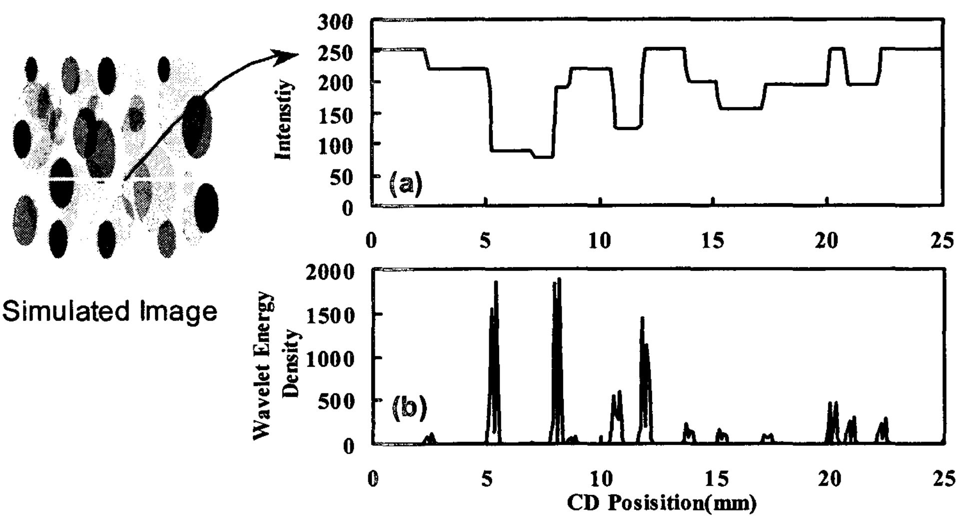


Figure 1. Edge Detection by Continuous Wavelet Transform

(a)Line Profile of Intensity Data (b)Local Wavelet Energy Profile

The sensitivity of this analysis makes it possible to define every flocs in data. Since the traditional image analysis method based on the threshold method defines the flocs with one threshold value[13;14], for example, average value of the intensities as shown figure 2,(b), the existence of defined floc by themethod greatly depends on the threshold value. This could lead to the miss definition of the flocs in different intensity scale. The local wavelet energy map shows the edges of all individual features including the small features in the larger features, as shown in Figure 2.

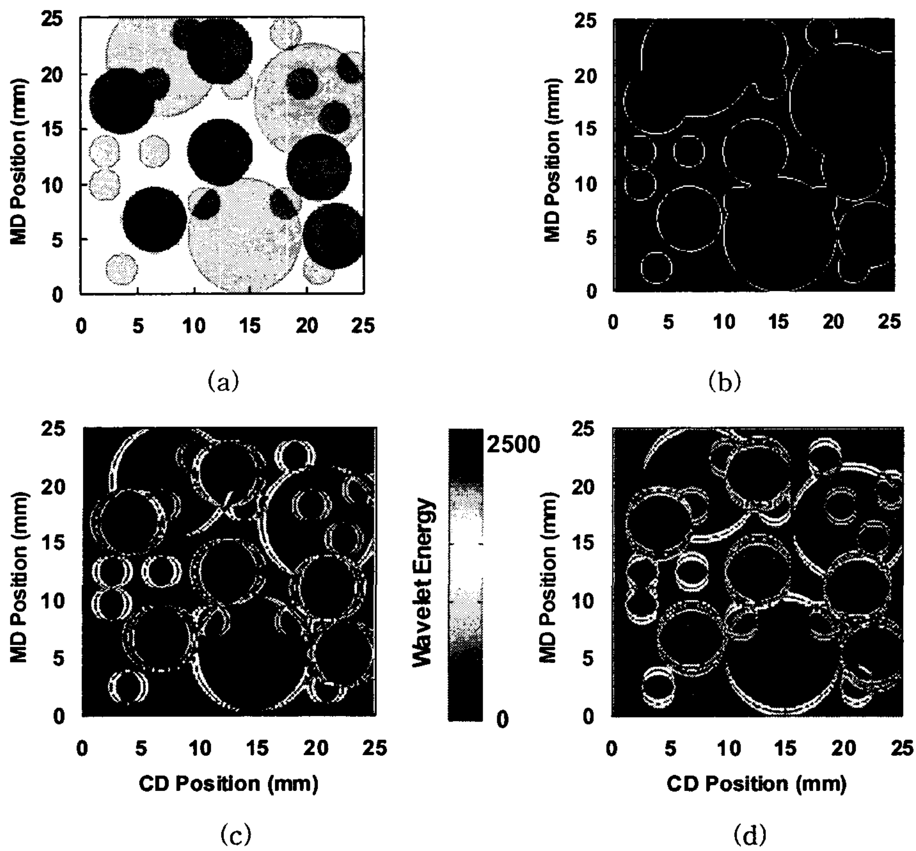


Figure 2. Edge detection of a simulated image

(a) A simulated image ,

(b) Edge image defined with image threshold method

(c) Local wavelet energy map calculated in CD

(d) Local wavelet energy map calculated in MD

The total amount of the wavelet energy in each direction, CD and MD, is depending on how long the edge in a direction which is same as the projected length in the direction and how the intensity of the floc is changed. Since the paper structure has stochastic properties, each floc can be assumed to have same Gaussian Intensity distribution in MD and CD. The difference between the total wavelet energy in both analyzed directions is originated from the length of floc boundaries. Therefore the ratio of the total wavelet energy in CD and MD directions can be used as an anisotropy index, *E*, as given by;

$$E = \frac{\sum \mathrm{E}_{\Psi,CD}(x,y)}{\sum \mathrm{E}_{\Psi,MD}(x,y)}$$

, where $\mathrm{E}_{\Psi,MD}(x,y)$: local wavelet energy calculated in MD (4)

The elongation of the flocs by various paper making processes in a certain direction could change the shape of flocs and resulted in the different aspect ratio of each floc, usually higher MD length than the CD length. This nature can be expressed as a anisotropy index higher than one.

3. Result and Discussion

3.1. Anisotropy in Simulated Images

In order to validate this analysis method, three groups of image data areused in this work. The first group data are the simple images created using a graphic program. Each image include a number of unit features, rectangle or ellipse, with different gray levels but with the same aspect ratio, such as 1:1, 1:1.25, 1:1.5,1:1.75, and 1:2. Three images for each aspect ratio are made and analyzed.

The second group of data are the stochastic images simulated the paper structure with the random disk model [15]. Although the original image has isotropy nature, the stretch of the image in MD with image analysis program can be considered as same effects of the stretchingduring papermaking process.

The local basis weight maps of the two handsheet samples are used. Each handsheet is made of mixture of 50% hardwood and 50% softwood of the standard bleached kraft pulp and has different formation which is controlled by the settling time during handsheet forming. The flocculated handsheet is settled 120 sec before forming. The same image analysis program is used for making the stretched images.

The change of anisotropy index depending on the aspect ratio of model unit or the elongation degree is shown in Figure 3.

The rectangle model images show very precise linear relationship between the aspect ratio of each rectangular model unit and the anisotropy index. This indicates the accuracy of this method is very high. However the application to the ellipse model images result in the bigger slope of the linear relationship although the ellipse model has still very high correlation. This higher slope may be originatedfrom the corner of the edge of each ellipse floc which can not be defined precisely by the wavelet transform. Although the anisotropy index could be affected by the shape of the flocs in each data, the real stochastic sample such as the two different handsheets and the stochastic random model shows very high correlation between the elongation ratio and the anisotropy index.

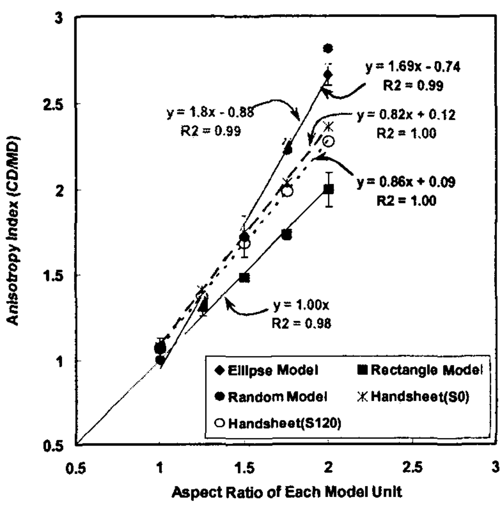
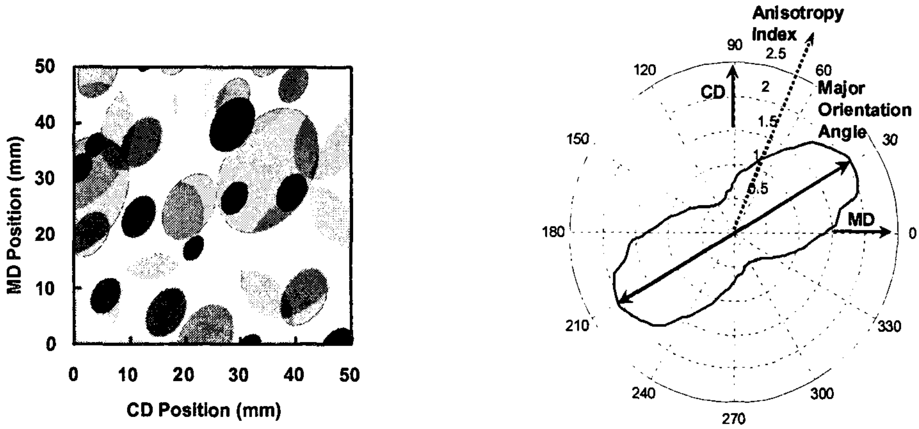


Figure 3. Relationship between the aspect ratio of individual model unit and anisotropy index of model image.

3.2. Measurement of the Major Orientation Angle

The anisotropic index is a function of the floc-orientation and can provide an excellent tool to obtain the orientation distribution and the major oriented angle of flocs as shown in Figure 4. The simulated image in which every ellipse features are rotated 30 degree clockwise. The anisotropy index of each image rotated every two degrees keep in increasing till 30 degree of rotation at which the anisotropy index becomes maximum value. The angle with the maximum anisotropy value can be considered as a major orientation angle of the image. As we expected, the minimum anisotropy value is found at 90 degreesrotation from the major orientation angle. This characteristic can be well represented in the polar plot in Figure 4 (b).



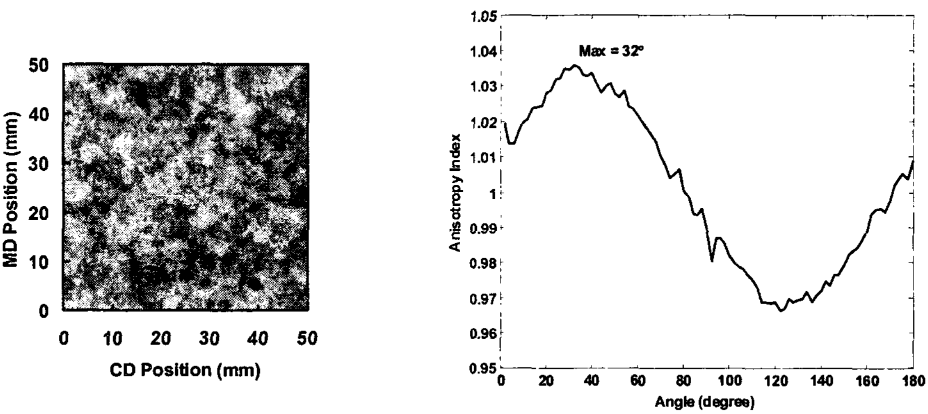
(a) (b)

Figure 4. The major orientation angle of a simulated image

(a) A simulated image, each unit is rotated 30 degree from MD

(b) Polar plot of anisotropy index

In order to apply this method on the real paper sample, the local basis weight map of a pilot machine made sample is analyzed. As shown in figure 5, although the absolute value of anisotropy index is not great, the major orientation of floc can be easily determined, 32 degree from MD.



(a) (b)

Figure 5. Major Orientation Angle of a Pilot Machine Sample with Wavelet Transform *(a) Local basis weight Map of a Pilot Machine Made Sample*

(b)Distribution of Anisotropy Index as a function of Analysis Angle (2 degree interval)

4. Conclusion

In this paper, the novel analysis method for measuring the anisotropy of deterministic features in a stochastic two dimensional data such as flocs in paper structure is introduced. The one dimensional continuous wavelet transform with a small scale range can quantify the amount of edge in MD and CD depending on the intensity of the features. The ratio of the total wavelet energy in both analyzed direction can be defined as a new anisotropy index. The applications to the simulated images show that this method can identify the edges with weighted wavelet energy depending on the intensity of each floc and provide accurate anisotropy index for the flocs.

The major orientation angle also can be determined. The anisotropy index becomes maximum value at the major orientation angle which can be obtained by rotating and analyzing data. The result of the pilot machine sample shows this method very sensitive to find out the major orientation angle. In case of the comparison of the local gloss variation of commercial samples, this method provided accurate differences in anisotropy by quantifying anisotropy of deterministic features in local gloss images.

Various properties and structure of paper has been frequently expressed as a two dimensional data, such as local density distribution map, topography map of coated materials, local component distribution map, local strain distribution map and so on. This method could be applied to those data set and provide more detailed information of structure and properties.

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