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Morphological Detection Method of Micron Wood Fiber Based on Skeleton Information

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Abstract

In order to compensate for the lack of mathematical model support for the traditional study of fiber morphology, using polynomial fitting to build microns wood fiber morphological model based on skeleton information. The fiber morphological category can be distinguished by taking derivation of the fitting function. In order to overcome the disadvantages of common morphological detection, the measurement of fiber length and its degree of curvature by using skeleton information is carried out. The length of the skeleton is approximated as the true length of the wood fiber, and the projected length can be calculated according to the endpoint coordinates. Finally, the fiber's curl index was obtained. Through the experiment, it has verified rationality of the fiber morphology model, and it is proved that the measurement method based on skeleton information can be better to avoid the influence of wood fiber morphological changes to the length measuring accuracy, moreover the fiber curl index can be calculated to quantify the bending degree and the type of wood fiber. It is an effective morphological detection method.

Keywords*: micron wood fiber; skeleton extraction; mathematical model; length measurement; curl index*

1. Introduction

With the rapid development of wood technology, wood fiber products can be seen everywhere in our daily life. Studies have shown that, in the pulp and paper industry, the fiber length is one of the important standards to measure the fiber raw material and pulp quality, and it is closely related with paper tearing, folding and other indicators [1].In the field of board processing, the morphology and texture of the fiber pose a great influence on the flexural strength. The raw material with large contact area can have better binding performance, and it is suitable for making music instruments and board material [2]. Morphological characteristics of wood fibers will affect the quality of its products, so that in order to produce more high-quality fiberboard, paper and other products, accurate detection of wood fiber morphology, such as length, width, and bending characteristics is very important.

The morphology detection methods of micro-nano scale objects are mainly laser diameter measurement, scanning electron microscopy, fiber quality analyzer, however, these conventional methods are generally time-consuming, expensive, and limited range of application [3]. In recent years, with the progress of science and technology, image processing technology has gradually been applied in the micro-nano morphological detection. The paper [4] proposed that aligning fiber and cutting to the same length, then we can obtain the number and length of the fiber by the image information after the dispenser handling, but this method is complicated and may cause inaccurate data during

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the experiment. The paper [5] proposed that using rectangle to fit the target area, so it is more suitable for wood flour and other granular objects. For the wood fiber which is easy to occur deformation, the deviation of fitting result is large, therefore the applicability of the algorithm is limited.

In order to detect the morphological features and establish the appropriate mathematical model, a proper and intuitive description method is needed. We can measure the fiber length, bending degree and other information by this form. The skeleton is a kind of shape description way that can reduce dimension. It is an important tool which can describe outline and reflect topological properties of the object more accurately [6]. So it is worth exploring the mathematical model based on skeleton information and detecting morphology of micron wood fiber.

2. Wood Fiber Morphological Modeling and Key Indicators Measurement

The regular wood fiber is generally presented as elongated needle, and its width is about 0.1-0.8mm, and the 2D image is approximate to the rectangle under microscope. Irregular wood fiber is prone to bending, bifurcation and other phenomena. Because the fiber length and bending degree are the important factors that affect the quality of the manufactured goods, it is necessary to measure the data accurately.

In view of the above features, if we want to detect wood fiber morphology more accurately, we will not only need to identify the region, but to find a suitable form of description, so as to establish an appropriate mathematical model. The skeleton can properly reflect the characteristics of the topological structure of objects, and it can more truly and objectively express their morphological characteristics using an appropriate method to get the wood fiber skeleton images, then we can detect the wood fiber length, curl index and other key information by reasonable statistical methods.

2.1 Micron Wood Fiber Skeleton Extraction

There are many ways to extract skeleton, one of them is the thinning algorithm. In the premise of not destroying the object's connectivity, unnecessary boundary point was eliminated until advancing to internal location [7]. Another is the central algorithm based on region, which can accurately locate position of the skeleton, but the complexity of the algorithm is very high. Then there is an algorithm based on distance transform, through finding the ridge of distance gradient to determine the skeleton, and it can improve the accuracy of location, but the connectivity needs to be further improved [8].

In this paper, we obtained the skeleton information of wood fiber based on vector inner product idea. Euclidean distance transform is used to determine the nearest edge element for each pixel in a binary image. A vector from each pixel that stops at the nearest edge element is defined as edge vector. By comparing the inner product of edge vector within 8-neighborhood of the pixel, the number of significant changes in direction can be determined, and the candidate skeleton points can be selected according to it. Finally, a complete skeleton is generated by extending process based on regression analysis.

Specific steps are as follows:

① Enter a binary image, and get the shortest distance of each pixel to the boundary points and the location of the nearest boundary points by the Euclidean distance transform.

② Construct the boundary vector of each internal pixel point.

③ Calculate the inner product between boundary vector of each internal pixel point and the boundary vectors of its 8- neighborhood pixels points.

④ Compare the symbol of inner product value within four directions respectively, if the symbol changed at least in three directions, then the point will be regarded as a candidate skeleton point.

⑤ Carry out regression analysis based on the discrete points of the branch skeleton.

⑥ Make stretching operation based on regression analysis, and if the coefficient of corresponding equation have the same symbol, the two branch skeleton will be connected together.

⑦ Output complete skeleton.

By observing a large number of experimental samples, we found that the two-dimensional morphology of micron wood fiber can be divided into four typical forms, such as “classes linear type”, “n-type”, “s-type”, “m-type”. Select the representative images of wood fibers, then extract skeleton information based on the idea of vector inner product. From Figure 1a to Figure 1d, there are original images of wood fiber; From Figure 1e to Figure 1h, there are binary images with skeleton information.

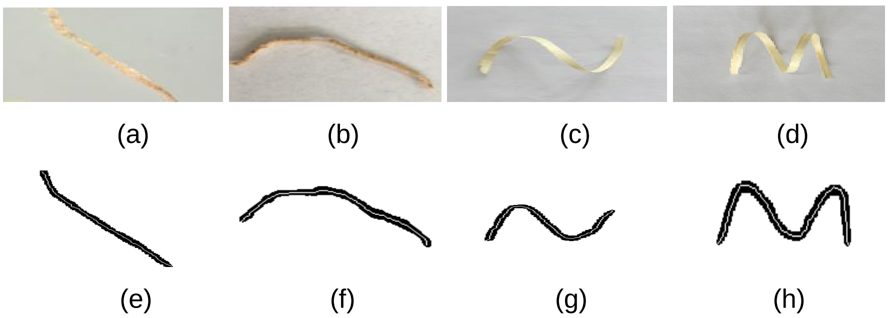


Figure 1. Skeleton Extraction Results

2.2 Establish Morphological Model Based on Skeleton Information

Skeleton information can visually display the morphological characters of micron wood fiber, but it still lacks support of the model, and the studies of mathematical model of morphological features are relatively rare. In order to provide more powerful mathematical support to the follow-up study, this paper use horizontal and vertical coordinates of the skeleton points to fit the fiber form, and to achieve the mathematical modeling of micron wood fiber morphology.

For the morphological characteristics of wood fibers, we used the least square method to establish the shape fitting equation. Using the method in Section 2.1, we can get the horizontal and vertical coordinates of skeleton points, and it assumes that the original data is $\{(x_i, y_i) | i = 1,2,\ldots,m\}$, which x_i represents the horizontal coordinates and y_i represents the vertical coordinates. The least squares fitting is to find function that can make the minimum of difference between function curves and observed values calculated by the Eq. (1), that is the smallest difference between original data(y_i)and fitting data($p(x_i)$) [9].

$$E^2 = \min_{p(x)\in\psi} \sum_{i=1}^{m} \left[p(x_i) - y_i \right]^2 \qquad (1)$$

The key of the least square method is that the geometry of the function $p(x_i)$ is close to the distribution of the discrete point, and the function is simple in form and easy to be calculated. The reliability and quality of the fitting curve are judged by R^2 and SSE, which calculated by the Eq. (2), and $\hat{y}_i$ represents the estimated value of y_i, $\bar{y}$ represents the average value of y_i. The value of R^2 is between 0 and 1, if it gets closer to 1, the fitting degree of the equation will be higher. The smaller SSE shows that the fitting curve is more approximate to the original data points [10-11].

$$\begin{cases} R^2 = 1 - \dfrac{SSE}{SST} \\ SSE = \sum_{i=1}^{m} (y_i - \hat{y}_i)^2 \\ SST = \sum_{i=1}^{m} (y_i - \bar{y}_i)^2 \end{cases} \quad (2)$$

Combined with the four typical morphology of micron wood fibers, based on the principle of least square method, we will select polynomial fitting, Gaussian fitting and Fourier fitting function to fit the skeleton points, and we will get better fitting curve by adjusting the number of parameters.

2.3 Measure Fiber Length Based on the Improved Freeman Algorithm

The length of skeleton is approximately considered as fiber length. Because the image takes the pixel as the unit, it belongs to the discrete data. The length of the discrete graphics can be calculated by Eq. (3) according to the theory proposed by A.Rosenfeld and A.C.Kak. The N_l indicates the number of pixel whose chain code is even number, and N_h indicates the number of pixel whose chain code is odd number. Counting the number of odd and even number in chain code by using appropriate method is the key to measure the length of skeleton.

$$L1 = N_l + \sqrt{2} N_h \quad (3)$$

Freeman algorithm is a kind of code expression of image contour, which is mainly applied to boundary scan of the closed area. The method is characterized by forming the target boundary by connecting several lines which have specific length and direction in turn, and the starting point is expressed by absolute coordinates while other points are expressed by continuous direction, and the algorithm stopped condition is scanning point coincides with the starting point.

Wood fiber is generally not presented as a ring end-to-end. By using the method in Section 2.1, the skeleton extracted from wood fiber can meet the connectivity, single pixel and other basic requirements, and does not form a closed interval. Therefore, traditional Freeman algorithm is not fully applicable for such non-closed image, and it will cause repeated chain codes. We should change the stopped condition in order to adapt to the characteristics of non- closed skeleton image.

The algorithm flow is as follows:

① Read micron wood fiber skeleton image.

②Traversing the image, and record the number of non-zero pixels within 8-neighborhood of skeleton points in array(N).

③ Traversing the array, if $N[i]=1$, the skeleton point(S_i) can be regarded as endpoint, otherwise it is considered as connected point. There are two endpoints and multiple connected points in the skeleton.

④ When $N[i]=N[j]=1$, we will compare i with j, and the smaller one is regarded as the starting point, then another one is considered as ending point of the scan.

⑤ Scan each skeleton in sequence, and get chain code of the skeleton points until the end.

Table1 gives the length data of micron wood fiber which is measured by skeleton information.

Table1. Length Data of Wood Fiber

No.	1	2	3	4
Fiber images				
Num of skeleton points	141	150	225	212
Skeleton length (pixel)	165.0244	181.0660	263.5219	251.3503

2.4 Measure Bending Degree of Micron Wood Fiber Based on Skeleton Information

Due to the complicated production environment and technology, processed micron wood fiber have shown curling with varying degrees, and the bending degree has diverse influence on softness, smoothness, permeability and has a closed connection with the quality. So it is very important to quantify the bending degree of wood fiber by using effective information.

Fiber curl, refers to the bending along the longitudinal direction of fiber to form a regular or irregular shape, and its two-dimensional image is a curve. Single fiber curly degree can be measured by curl index [12]. For different forms of wood fiber, the skeleton information can be used as a quantitative representation. For a wood fiber with multiple curves, the curl index is calculated by multiplying corresponding weight factor, which is defined as Eq. (4). L represents the length of the whole wood fiber, and L_i represents the length of the wood fiber in single curl; K_i represents the projected length of the two endpoints, and n represents the number of curls, and its value will not be more than 2 within a single wood fiber because of the effect of length, that is $n \le 2$.

$$Curl = \sum_{i=1}^{n} \left(\frac{L_i}{K_i} - 1 \right) * \frac{L_i}{L} \tag{4}$$

The length that we obtained by the method in Section 2.3 can be regarded as the true length of wood fiber, so how to get the projected length of wood fiber is the key to measure bending degree.

The matrix can be used to represent a binary image, so the projected length of wood fiber in a direction can be calculated by using Eq. (5). And in this formula the two endpoints of wood fiber image within single curl are (x_1, y_1) and (x_2, y_2).

$$K_i = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{5}$$

According to curled depth and length, we can divide the curling degree into 3 types:

① Weak curl: the arc of curl is less than half a circle, and the fiber is relatively straight, and the number of curls is less.

② Usual curl: the wave shape is approximate to a half circle.

③ Strong curl: the amplitude of curl is higher, and the number of curls is more.

The curled types of wood fiber can be distinguished by $Curl$, and we use semi-circle as compared reference, $Curl = \frac{\pi R}{2R} - 1 = \frac{\pi}{2} - 1 \approx 0.57$.

3 Experimental Results and Analysis

3.1 Verify Validity of the Mathematical Model

During the experiment of curve fitting, we have tried polynomial fitting, Gaussian fitting, and Fourier fitting, Table 2 is the statistical results of R^2 and SSE among the three fitting functions.

Table 2. Correlated Coefficient and Residual Value of Fitting

No.	Polynomial fitting		Gaussian fitting		Fourier fitting	
	R^2	SSE	R^2	SSE	R^2	SSE
1	0.9941	300.7	0.9948	352.9	0.9955	305.8
2	0.9648	525.7	0.9615	575.2	0.9620	567.1
3	0.9833	241.3	0.9709	270.9	0.9601	371.2
4	0.9883	247	0.9786	373	0.9844	268
5	0.9975	571.4	0.9974	577.8	0.9973	608.8
6	0.9966	2046	0.9918	2190	0.9922	2135
7	0.9973	642.7	0.9787	2084	0.9970	713.9
8	0.9938	143	0.9824	307.7	0.9880	277.1

The results show that fitting quality of the three kinds of method are high, but the principle of Fourier fitting is more complex and the SSE of Gaussian fitting are relatively higher, while the polynomial function which can complete fitting in lower terms is simple and standardized, so it will not affect stability of the equation, moreover, the fitting precision is high. Therefore, using the polynomial function to fit wood fiber shape, we can build better mathematical models.

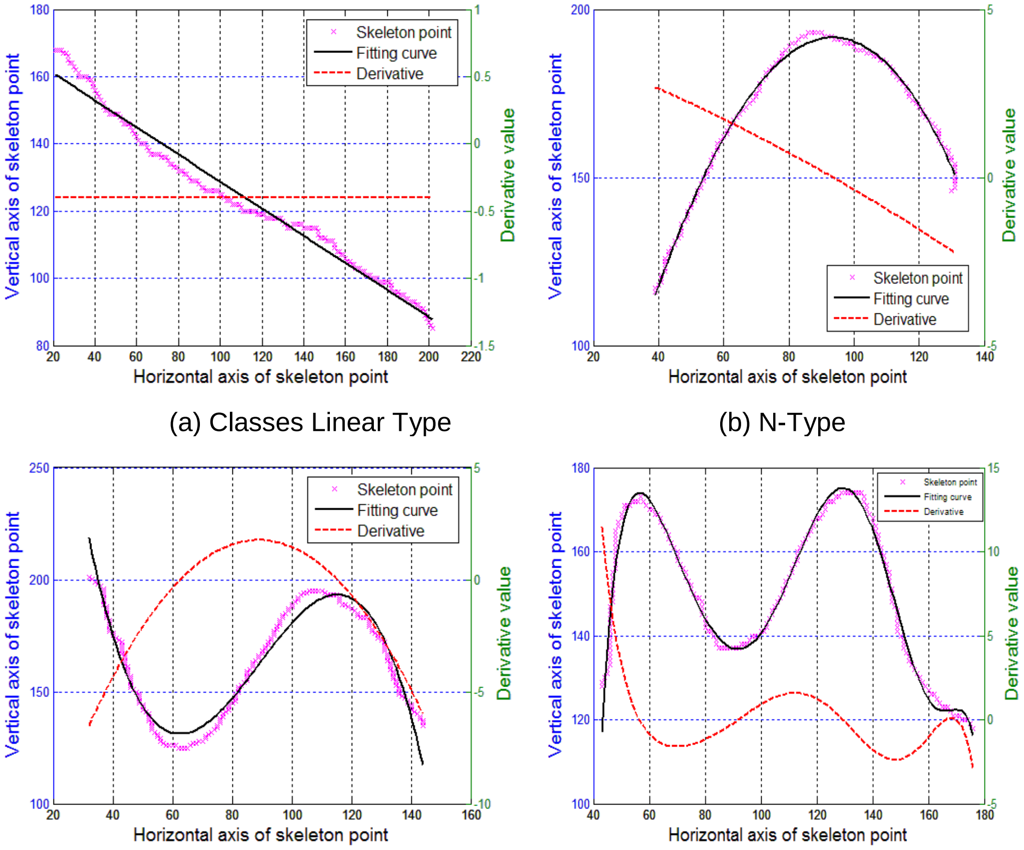
It is proved that the polynomial functions fitted by skeleton points can well describe the shape of wood fiber, because the R^2 is above 0.96, and the SSE is the smallest among three methods. We can use the Eq. (6) to build an effective model, which can provide better mathematical support for the quantitative relationship among the morphological parameters.

$$p(x) = \sum_{k=0}^{n} a_k x^k \tag{6}$$

a_k is a real number that represents the coefficient of equation, and the fitting coefficients are different in different fiber images.

Aim to realize the research of wood fiber morphology by mathematical model, we draw the derivative of fitting function. Combined the quantity of points whose derivative equals zero and the changes situation of absolute value, we can judge the type of fiber morphology. Figure 2 is the wood fiber fitting curve and its derivative diagram.

In the Figure 2a, the value of derivative is not zero, and this indicates that there is no inflection in the fitting function, which demonstrates the morphology of wood fiber approximates to straight line as “classes linear type”; In the Figure 2b, there is one point whose derivative is zero, and the absolute values of derivative first decrease and then increase, so it indicates that there is a inflection, and the fiber can be regarded as "n-type"; In the Figure 2c, there has two points whose derivative is zero, and the absolute value experienced decreasing, increasing, and re-decreasing, then re-increasing, so we infer the fiber can be showed as "s-type"; Similarly, we can infer the fiber in Figure 2d appear as "m-type" by analyzing the variation of absolute value.



(a) Classes Linear Type (b) N-Type

(c) S-Type (d) M-Type

Figure 2. Wood Fiber Fitting Curve and Its Derivative Diagram

3.2 Length Measurement and Analysis of Micron Wood Fiber

In order to testify the effectiveness of the length measurement based on skeleton information, we make a contrast experiment on the samples with the methods of line segment, paper [5] and this paper. The method of paper [5] constructs the minimum circumscribed rectangle of the target image, and then measures the length of the rectangle. When using the line segment method, we need to make wood fiber straight and connect ends with a straight line, then the pixels of this straight line indicate its length, and the data we got through this method is regarded as the ideal value. Experimental results are shown in Table 3, where the relative error is calculated as the Eq. (7) and Eq. (8):

$$\delta_1 = \left| \frac{\text{Rectangle fitting} - \text{Line segment}}{\text{Line segment}} \right| \tag{7}$$

$$\delta_2 = \left| \frac{\text{This paper} - \text{Line segment}}{\text{Line segment}} \right| \tag{8}$$

Table 3. Comparative Results of Different Measurement Methods

No.	Paper [5] (pixel)	Line segment (pixel)	δ_1	This paper (pixel)	δ_2
1	245.1448	435	43.64%	443.2447	1.90%
2	202.4826	215	5.82%	220.3087	2.47%
3	149.3977	160	6.63%	165.0244	3.14%
4	142.5043	135	5.56%	139.6274	3.43%
5	244.1600	256	4.63%	261.2620	2.06%
6	273.0511	290	5.84%	297.3209	2.52%
7	128.1106	120	6.76%	123.1960	2.66%
Average	--	--	11.27%	--	2.60%

It is not hard to find that the relative error of rectangle fitting method is larger, with an average of 11.27%, and for obviously curved wood fiber, the error of measurement is up to 43.64%. The relative error of the method in this paper is about 2.60%, so using skeleton information, we can measure the length of micron wood fiber in a more accurate way. The reasons for the errors are the following:

① The rectangle fitting method is only simple to measure length of the rectangle when the minimum circumscribed rectangle is constructed, without considering the morphological features of wood fiber. If fiber occurs bending, the fitting rectangle cannot accurately describe its shape, so the measurement of length will appear larger deviation.

② The length measured by the line segment method is too ideal. Because the surface of wood fiber is not smooth, and there may be a phenomenon of local deletion, using line segment method can't make it completely straight. To some extent, it has influenced the accuracy of measured data.

③ The key of this paper is how to extract the skeleton image, which is conducive to measure length of wood fiber. Skeleton extraction based on vector inner product can ensure the connectivity and integrity of skeleton, and make the position accurate, and overcome the disturbance of boundary. These can provide an important foundation for measuring fiber length.

In summary, the line segment method needs rich experience and careful operation; and rectangle fitting method can't overcome the difficulty which caused by changes of wood fiber shape. To some extent, the method in this paper can overcome the interference caused by morphological changes of wood fibers, so it is an effective method for length measurement.

3.3 Measurement and Analysis of Micron Wood Fiber Curl Index

In Section 3.2, we have proven the method based on skeleton information is valid, and we can obtain the projected length of fiber by matrix operations. Taking the data into Eq. (5), we will get curl index of micron wood fiber. Table 4 shows the curl index of micron wood fiber.

Table 4. Curl Index of Wood Fiber

No.	Real length (pixel)	Projected length (pixel)	Curl index
1	443.2447	232.1551	0.9093
2	171.0660	97.0824	0.7621
3	207.5635	142.9405	0.4521
4	154.8234	118.0381	0.3116
5	183.3797	140.9433	0.3011
6	297.3209	264.3785	0.1246
7	220.3087	199.1231	0.1064
8	123.1960	112.1606	0.0984

By observing many micro-images of wood fibers and analyzing the data, we found that the morphology and curl index have a close contact, and there are certain tendency in curling classification:

① When $Curl = 0$, representing the fiber's length is equal to projected length, and the wood fiber presents as straight state. Affected by processing conditions, the absolutely straight wood fibers are extremely rare, so we only regard the fibers whose curl index is not high as "classes linear type".

② When $Curl$ for certain values, such as 0.9093, 0.4521, 0.3116 *etc.*, wood fibers exhibit different degrees of crimped state; and the value of curl index is greater, the micron wood fiber is more obviously curved in micro-image.

③ As described in Section 2.4, in semi-circle $Curl \approx 0.57$, most of the samples' curl index are less than the value, so micron wood fibers belong to the type of weak curl mostly. There are also the cases that curl index is greater than 0.57, usually such wood fibers presented as "s-type" or "m-type ".

4. Conclusion

In this paper, it built morphological model of micron wood fiber based on skeleton information, and combined with derivative of fitting function to judge the morphological type of fiber, so it can provide powerful mathematical support for further quantitative research. For the bending propensity of wood fiber, this paper proposed a way to measure length and curl index based on skeleton. Through experiments and analysis, it is proved that the method can effectively avoid the influence made by morphological changes of fibers for the accuracy of data; and the curl index calculated by skeleton information can be used to distinguish the curling degree and types of wood fibers in a quantitative way. The length and curl index of wood fibers can help adjust parameters of wood processing, which has great significance for intelligent processing industry of micron wood fibers.

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