Extraction Method of Microscopic Image Feature of Cotton Fiber Cross Section

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Abstract. The micro-section image analysis is an effective method to measure cotton fiber maturity directly. However, the accuracies of the existing image segmentation and contour extraction algorithms were limited by the extraction of cotton fiber cross-section features. Therefore, the paper first binarized the cotton fiber cross-section micro image with the image processing software programmed by VC++, and then extracted the contours of its outer layer, inner layer and cavity, and finally calculated its geometric features. Based on statistics of these geometric features, a judgment model was established to remove the low quality cross sections such as pseudo-cross sections and separate adhesion cross sections, so as to improve the geometric feature extraction effect and the maturity estimation accuracy of cotton fiber cell. The results showed that, compared with the artificial subjective judgment, the cotton fiber cross-section feature extraction method proposed in this paper could not only solve the problem of unable to determine the geometric characteristics caused by cotton fiber adhesion and other interference factors, but also reduce the identification error rate from 0.073 to 0.038, so as to better judge the quality of cotton fiber at harvest time, and infer the possible influencing factors.

1. Introduction
The maturity of cotton fiber affected its quality [1]. The analysis of microimage of cotton fiber cross-section was one of the most direct and accurate methods to evaluate the maturity of cotton fiber [2-4], and its success depended upon the accurate extraction of features of cross-section of cotton fiber [1,5]. However, the factors such as glass slide sample defects, impurity interference, uneven exposure, unobvious borders and adhesion all affected the effective recognition and accurate extraction of image features [4]. In this paper, a method for segmentation of cotton fiber cross-section microscopic image and boundary contour feature extraction was developed, which could automatically extract and effectively detect the real cotton fiber cross-section, thereby improving the accuracy of cotton fiber maturity assessment [6].

2. Materials and Methods

2.1. Materials
The white fine-staple cotton originated in Central America had a higher yield, a longer fiber and a better quality, and widely planted in China. Its fiber length was 25~35 mm, the linear density was 4700~6400, and the strength was about 4.5 cN.
2.2. Methods

2.2.1. Fabrication of cotton fiber cross section and microscopic image acquisition

The cotton fiber sample was immersed in a coagulable liquid at a polyvinyl chloride (PVC) tube, and loosen as much as possible to avoid adhesion. The ultraviolet radiation was used to solidify the liquid. The solidified PVC was cut into a microscopic slice with a thickness of 0.2 mm, and the cross-section slices of cotton fiber on a glass slide were further spread by a dissolving solution so as to improve the slice transmittance of light and increase the fiber separation degree of microscopic image [5].

An optical microscope equipped with a high-resolution (2560×1920 or 4272×2848 pixels) and a wide-angle digital camera was used to obtain microscopic images of cotton fiber cross-sections.

2.2.2. Feature extraction of cotton fiber cross-section microscopic image

(1) Characteristic parameters of cotton fiber cross-section microscopic image

This paper developed an image processing program based on Microsoft Visual Studio 2010 and OpenCV 2.4.10 software system. The minimum hardware requirements for its operation were: main frequency 2.99 GHz, 4 GB RAM, and Windows 7 operating system. The outer contour, inner contour and cavity contour of cotton fiber cell wall which characterized the structural characteristics of cotton fiber cross-section were extracted by the adaptive threshold method (Adaptive Threshold function) derived from OpenCV 2.4.10. According to the magnification and image resolution of microscope, the extraction threshold values of geometric feature parameter of cotton fiber cross-section microscopic image were shown in Table 1.

Table 1. Parameter thresholds of geometric feature of cotton fiber cross-section microscopic image.

| Parameter | Value (unit) | Meaning |
|-----------|--------------|---------|
| $T_{angle}$ | 0.785 (Radian) | Concave and convex point angle threshold |
| $T_{min}$ | 60 | Lower threshold of contour length |
| $T_{max}$ | 300 | Upper threshold of contour length |
| $A_{min}$ | 160 | Lower threshold of area |
| $A_{max}$ | 5600 | Upper threshold of area |
| $C$ | 2.4 | Roundness threshold |
| $AR$ | 0.9 | Threshold of area difference between inner and outer contour |
| $dis$ | 5 | Image processing display signal parameters |
| $a'$ | 0.349 (Radian) | Auxiliary parameters during processing |

(2) Pretreatment of cotton fiber cross-section microscopic image

Image segmentation The Adaptive Threshold function of Open CV was used to segment the cotton fiber cross-section microscopic images. First, the gray value distribution of all neighboring pixels of each pixel in the cotton fiber microscopic image was counted, and their maximum entropy threshold was calculated; then, the image was separated as follows: if the gray value of the pixel was higher than the maximum entropy threshold, the pixel was determined to be the target pixel; otherwise, the pixel was determined as the background pixel [7]; the whole image was thus divided into two parts, the target region and the background region [8].

Image boundary extraction The image gray value gradients and the edge detection operators could be used to characterize the image boundaries. The differentiation technology was used to extract the image boundary [9]. The pixel $(x, y)$ gray value gradient was calculated by the following formula:

$$
\nabla f(x, y) = f_x \cdot i + f_y \cdot j
$$

(1)
Where, $\nabla f(x,y)$ contained the gray value change information, and the $i, j$ were the unit vector in the horizontal and vertical direction, respectively.

The edge detection operator $e(x,y)$ was calculated by the following formula:

$$e(x, y) = \sqrt{f_x^2 + f_y^2}$$  \hspace{1cm} (2)

Here, $f_x, f_y$ were the partial derivative of function $f$ to $x$ and $y$.

(3) Feature extraction of cotton fiber cross-section microscopic image

There were a lot of noise and other interference at the boundary of the cotton fiber cross-section microscopic image. The shape contour and the spatial relationship were used to extract the boundary contour features of the cotton fiber cross-section microscopic image after segmentation [10].

Calculation of cotton fiber cross-section features

The pixels arranged as counterclockwise $(c_{0}, c_{1}, ..., c_{N})$ was the number of pixel in the contour $c$.

Among them, $T_{angle}$ was the angle threshold for judging concave or convex points, and was $45^\circ$ in this paper; $K_s$ was the length step of length which was used to adjust the calculation accuracy of the concave and convex point at the calculation point $p_k$, which was 5 in this paper.

The $\theta$ of cotton fiber could be calculated by the following formula [1]:

$$\theta = \frac{4\pi A_f}{(P_f)^2} = \frac{4\pi (Area(c_f)-Area(c_l))}{(Length(c_f))^2}$$  \hspace{1cm} (6)

Here, $A_f$ and $P_f$ were the area and circumference of cotton fiber wall surrounded by $c_f$ and $c_l$.

The mean value ($M_g$), standard deviation ($SD_g$), skewness ($S_g$) and peak value ($K_g$) of maturities of all cotton fiber sections in an image were calculated to describe their distribution characteristics [12].

Identification of cotton fiber cross-section

The geometric characteristics of cotton fiber cross-section included the length (perimeter), area and roundness, etc., and their size depended on the maturity of each fiber. According to the above geometric features, the contour and noise of cotton fibers could be distinguished.

After extracting the geometric features of any contour, a qualified inner contour or outer contour was judged according to the following rules.

$$Q(c) = \left(T_{E}^{min} \leq Length(c) \leq T_{E}^{max}\right) \land \left(T_{A}^{min} \leq Area(c) \leq T_{A}^{max}\right) \land \left(Circularity(c) > T_{C}\right)$$  \hspace{1cm} (7)
Here, $0 \leq T_c \leq 1$. If both $Q_c(c_o)$ and $Q_c(c_i)$ were true, then $c_o$ and $c_i$ might be the outer and inner contour of a cotton fiber section. Otherwise, it might be a contour of a defective cross-section or a false contour that needed to be filtered out.

According the following formula, the spatial position relationship between the outer contour $c_o$, the inner contour $c_i$ and the cavity contour $c_c$ of cotton fiber section were used to determine whether the triple $(c_o, c_i, c_c)$ constituted a real cotton fiber section:

$$Q_{oi}(c_o, c_i, c_c) = \left( \text{Region}(c_o) \supset \text{Region}(c_i) \supset \text{Region}(c_c) \right) \land \left( \text{Length}(c_o) \geq \text{Length}(c_i) \geq \text{Length}(c_c) \right) \land Q_c(c_o) \land Q_c(c_i) \land \left( \frac{\text{Area}(c_o) - \text{Area}(c_c)}{\text{Area}(c_o)} \right) \leq T_{AR}$$

Among them, $\text{Region}(\cdot)$ was a function for calculating the image area enclosed by the contour $Q_{oi}(c_o, c_i, c_c)$. $T_{AR}$ was usually 0.9 based on experience, because the inner and outer contour of general cross section were close to each other. If $Q_{oi}(c_o, c_i, c_c)$ was true, $(c_o, c_i, c_c)$ was a real cotton fiber cross section; Otherwise, further processing of the contour was needed to determine whether $(c_o, c_i, c_c)$ came from a real cotton fiber cross section. A qualified cotton fiber section met the two conditions of formula (7) and (8).

(4) Extracting cotton fiber section based on geometric features

Extraction optimization of the inner and outer contours

The factors such as improper microscope focal length, dust and image noise might cause errors in extraction of the cross-sectional features [13]. Thus, the local multi-threshold segmentation method was used to optimize the extraction of outer contours.

The adjacent point ($\text{neighbor}(i, j)$) of any pixel $I(i, j)$ in the image $I$ was defined as a point on a square or circle with $I(i, j)$ as the center, and the adaptive threshold of this pixel point was denoted as $T_{\text{neighbor}(i, j)}$. The image area enclosed by the outer contour $c_o$, which was extracted by the adaptive threshold method, was denoted as the $\text{Region}(c_o)$. The following formula was used to calculate the average threshold $T_{av}$:

$$T_{av} = \frac{\sum_{l(i, j) \in \text{Region}(c_o)} T_{\text{neighbor}(i, j)}}{M}$$

Here, $M$ is the number of pixels in area $\text{Region}(c_o)$.

The $H(c_o)$ was the convex hull of the image area $\text{Region}(c_o)$ surrounded by the contour, and the threshold sequence $\{T_{av} - \Delta T, T_{av} - \Delta T + 1, \ldots, T_{av} + \Delta T - 1, T_{av} + \Delta T\}$ was used to segment $H(c_o)$ successively so as to extract the correct outer contour. Here, $\Delta T$ was 20.

The $C_{2\Delta T}$ was used to denote a series of contours obtained by segment of $H(c_o)$ with the above threshold sequence. The $c_o'$ represented the optimal contour in $c_o$, which could be searched according to the following formula:

$$c_o' = \arg \min_{c \in C_{2\Delta T}} \text{Length}(c)$$

where, $\text{BBox}(c)$ was the function for calculating the rectangle bounded by $c$. The $\text{BBox}(c) \cong \text{BBox}(c_o)$ meant that the difference between the bounding rectangles of $c$ and $c_o$ was less than the preset value, here was 4 pixels. The reason why equation (7) was not used to optimize the contour decision was that this equation only used the geometric features, and its identification for an inner or outer contour was too lenient, and thus the obtained contour was not the most ideal. The bounding box method (equation 10) used here was simple and quick to judge, and was better for the optimization of external contour.

The $C_c$ was the set of contours contained by $c_o$ during the adaptive threshold segmentation, and the optimized inner contour $c_i'$ could be searched according to the following formula:

$$C_{i'} = \left\{ c \in C_c \cup C_{2\Delta T} \land \left( \text{Region}(c_o') \supset \text{Region}(c) \right) \land \left( \exists c' \in C_c \cup C_{2\Delta T} \left( \text{Region}(c') \supset \text{Region}(c) \right) \right) \right\}$$

Separation of the adhesive cross-section of cotton fiber

The sticky cross-section of cotton fiber might cause an error in extraction of the outer contour. All the contours contained by the adhesion
outer contour $C_0$ were denoted as $C_i$. Calculated all the concave points ($p_0, p_1, ..., p_{N-1}$, $N$ was the number of concave points) of the outer contour $C_0$. Let the current processed contour $C=C_0$, and the contour $C$ could be separated by the methods and steps described above.

3. Results and analysis

3.1. Possible features of cross-section microscopic image of cotton fiber
The brightness and focal length of the image under the high-resolution and wide field of view were easy to change, which reduced the effectiveness of extraction of microimage features of cotton fiber cross-section with special shapes and characteristics, and generated many cotton fiber cross-sections of with different types: such as higher maturity but smaller cavity; lower maturity but larger cavity; lower maturity, larger cavity and flattened spindle shape; lower maturity, larger cavity, and self-adhesion after flattening; affected by dust or other impurities; two overlapped; adhesion; adhesion of cell wall and cavity; and contact with cavity boundary.

3.2. Selection of neighborhood size of cotton fiber cross-section microscopic image
Figure 1 was the partial micrograph of the test cotton fiber. Figure 2 showed the segmentation effect of the cotton fiber cross-section microscopic image when the Gaussian method was used to calculate the adaptive threshold and the neighborhood size was different. It was obvious that the Gaussian method could suppress the background noise well [10]. The size of pixel neighborhood had a great influence on the image segmentation effect. If it was too small or too large, it might cause cross-section adhesion and additional noise boundaries, which increased the difficulty of interface extraction [14]. According to the sharpness of the image in Figure 2, the neighborhood pixel size was selected as 15*15.

3.3. Feature extraction of cotton fiber cross section microscopic image
3.3.1. Types of cotton fiber profile
The high-power optical microscope was used to observe and collect the microscopic images of a single cotton fiber section. Figure 3(a) was the cotton fiber with poor maturity, and Figure 3(b) was the cotton fiber with better maturity, although their outer circumferences were close to each other. The cotton fibers with better maturity had thicker walls and smaller cavities, the cotton fibers with poorer maturity had thinner walls and larger cavities so as to be easily flattened by external forces [15].

![Figure 3](image1)

(a) (b)

Figure 3. Microscopic image of cotton fiber cross-section (magnification: 4000). (a) Cotton fiber cross section with poor maturity; (b) Cotton fiber section cross with good maturity.

![Figure 4](image2)

Figure 4. Three outlines of cotton fiber section.

![Figure 5](image3)

Figure 5. Cross-sections and outlines of defective cotton fibers. (a) Scratch; (b) Adhesion; (c) Self-adhesion.

A typical microscopic image of a single cotton fiber section was shown in the left of Figure 4, because the gray value of the outer contour and cavity were low under the light shadow, and that of the wall and background was higher due to the good light. The left image in Figure 4 was segmented and the boundaries of different regions were extracted. The results were shown in the right of Figure 4: the outer contour–[C_o], the inner contour–[C_i], and the cavity contour–[C_l]. Ideally, the [C_o] and [C_i] were coaxially parallel and very close [15]. Therefore, the triple ([C_o],[C_i],[C_l]) was used to describe the cross section of a cotton fiber.

Figure 5(a) was a slide-scratched cross section, the [C_o] and [C_l] could not be extracted correctly due to internal contour and cavity adhesion; Figure 5(b) was a triconglutination section, the [C_o] could not be extracted correctly; and Figure 5(c) was a self-adhesive section, the [C_o], [C_i] and [C_l] could not be extracted correctly. The correctly analysis of size, shape and position of the three contours, and detection and correction of contour defects were needed for accurately assessing of cotton fiber maturity.

3.3.2. Effectiveness of cotton fiber section feature algorithm
Figure 2 showed that a lot of false contours would produce during the image segmentation by an adaptive threshold [16]; this was true even for figure 2(d), which was best segmented. In order to test the validity of equation (7) to determine the inner and outer contours of cotton fiber cross-section, the filtering test was performed on Figure 2(d), and only the contours satisfying equation (7) were retained. In the test, the $T_{C_{min}}$ and $T_{C_{max}}$ were set to 60 and 1200, $T_{A_{min}}$ and $T_{A_{max}}$ were set to 150 and 2400, and $T_{E}$ was set to 2.4, respectively. The contour information after filtering was shown in Figure 6. It could
be seen that most of the false contours caused by background noise had been successfully filtered out, while the real cotton fiber cross-sectional contours including the single cotton fiber cross-section and the bonded cotton fiber cross-section were successfully retained, which showed that the method of feature calculation designed here and the contour discrimination were effective.

![Figure 6. Filtering test results of cotton fiber microscopic image contour in figure 2(d). Resolution 2560×1920, scale 1:220.](image)

![Figure 7. The optimized extraction of the cross-sectional profile of three-bonded cotton fiber. Scale 1:1450.](image)

3.4 Extraction effects of cross-section geometric features of cotton fibers

The segmenting results of cotton fiber cross-section microscopic images with an adaptive threshold were generally better. However, due to the short focal length of the microscope, if the cut thickness of the cotton fiber section were not uniform, the imaging quality of different areas of the section would be inconsistent, and the gray value would fluctuate greatly, resulting in extraction errors. In addition, the effects of dust and image acquisition noise might have the similar results.

Figure 7 showed the optimization process of the cross-sectional outline of the three-bonded cotton fiber. Figure 7(a) was the contours extracted after adaptive threshold segmentation, figure 7(b) to figure 7(e) were partial contours extracted from partial image segmentation using the threshold sequence $[T_{av} - 20, T_{av} - 19, ..., T_{av} + 19, T_{av} + 20]$. When the threshold was equal to $T_{av} - 13$, the extracted outer contour was better.

The concave points of outer contour of Figure 7(e) calculated according to the equation (3) (marked by yellow dots) were shown in Figure 8.

Figure 9 was the separation process of the three-bonded cotton fiber section shown in Figure 8. The separation of the 12 cotton fiber cross-section microscopic images with a resolution of 4272×2848 showed that this method could successfully separate 83.1% of the bonded cotton fiber cross-section. However, this method was invalid if multiple cotton fiber sections were adhered to form clusters[17]. Fortunately, only 6% of the 12 images was adhesion clusters, so it had little effect on the estimation of the maturity of cotton fiber samples, and thus did not involve the separation of the adhesion clusters in this paper.

After all the cross-sections of the image were extracted, the cotton fiber wall was positioned at the minimum gray value between the inner and outer contours, and the inner and outer contours were synthesized to obtain the final contour of the cotton fiber wall. The test results of cotton fiber maturity assessment ability were shown in figure 10. The average error rate, maximum error rate, and minimum error rate of maturity estimated by only the inner contour were 0.073, 0.114, and 0.038, respectively. The average error rate and the maximum error rate and the minimum error rate calculated according to
the final contour of the cotton fiber wall were 0.038, 0.062, and 0.018, respectively. Thus, compared with the former method, the error rate of the latter method was reduced by 47.95%, 45.61% and 52.63% respectively; it meant that the use of the cotton fiber microscopic image feature extraction method proposed in this paper could significantly improve the accuracy of cotton fiber maturity estimation. Because the effectiveness of feature extraction of cotton fiber cross-section microscopic images, such as the calculation accuracy of circumference and area of cotton fiber wall and cavity contour directly affected that of maturity estimation [18].

Figure 8. The concave points of outer contour of the three-bonded cotton fiber section in Figure 7(e). Resolution, 4272 × 2848; Scale 1:1250.

Figure 9. The separation process of the three-bonded cotton fiber section in Figure 8. Resolution 4272 × 2848, Scales 1:1300.

(a) Calculate the concave point;
(b) Find the concave point pair of 3 and 8, and separate the left cotton fiber section;
(c) Update and calculate the concave point of the remaining contour;
(d) Find the concave point pair of 5 and 7, and separate cross section of cotton fiber on the right;
(e) End of separation.
Figure 10. Error rates of different estimation methods of cotton fiber maturity.

4. Conclusion and Outlook
The paper proposed a new method for extracting geometric features of cotton fiber cross-section microscopic images. The comprehensive use of outer contour, inner contour, and cavity contour geometric features of the cotton fiber cross-section was more robust than the only use of the outer contour or the inner contour feature of cotton fiber cross-section. The information of different contours could mutually corrected each other [19]; it could effectively segment large groups of adhered cotton fibers, and significantly reduced the average error rate of cotton fiber maturity evaluation; the computer programming and digital image processing technology were better than the manual visual inspection and the hand feeling detection. The method had a higher accuracy and efficiency [10]. It was expected that this method would be applied to the quality detection of other fibers after a practical testing and continuous improvement.

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