

Fast processing of foreign fiber images by image blocking



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ABSTRACT

In the textile industry, it is always the case that cotton products are constitutive of many types of foreign fibers which affect the overall quality of cotton products. As the foundation of the foreign fiber automated inspection, image process exerts a critical impact on the process of foreign fiber identification. This paper presents a new approach for the fast processing of foreign fiber images. This approach includes five main steps, image block, image pre-decision, image background extraction, image enhancement and segmentation, and image connection. At first, the captured color images were transformed into gray-scale images; followed by the inversion of gray-scale of the transformed images; then the whole image was divided into several blocks. Thereafter, the subsequent step is to judge which image block contains the target foreign fiber image through image pre-decision. Then we segment the image block via OSTU which possibly contains target images after background eradication and image strengthening. Finally, we connect those relevant segmented image blocks to get an intact and clear foreign fiber target image. The experimental result shows that this method of segmentation has the advantage of accuracy and speed over the other segmentation methods. On the other hand, this method also connects the target image that produce fractures therefore getting an intact and clear foreign fiber target image.

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1. Introduction

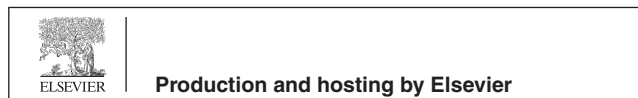
Foreign fibers in cotton refer to those non-cotton fibers and dyed fibers, such as hairs, binding ropes, plastic films, candy

wrappers, and polypropylene twines. Foreign fibers are mixed with cotton during picking, storing, drying, transporting, purchasing, and processing, are difficult to remove in the spinning process, and can cause yarn breakage, even reducing the efficiency. Even low content of foreign fibers in cotton, especially in lint, will seriously affect the quality of the final cotton textile products, as they may debase the strength of the yarn, and are not easily dyed [21]. Since the price of the cotton for sale is affected by the content of foreign fibers in it, the cotton farmers and traders are willing to keep the foreign fibers away to obtain a high price. This will lead to great economic loss for the cotton textile enterprises. Two main factors may lead to a high level of foreign fiber content in

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cotton. One is the inappropriate picking technique. The foreign fibers are generally removed manually using human visual inspection, or mechanically using automated visual inspection [12,19]. When most western countries are using machines to pick up cotton automatically, Chinese cotton farmers in most regions are still picking cotton manually and putting them in polypropylene bags. Currently, foreign fibers are generally removed by hand picking methods using human visual inspection in most Chinese enterprises, which is time consuming and inefficient. So a machine vision system for online measurement of the content of foreign fibers in cotton is now being studied. High quality image acquisition, fast image processing, effective feature extraction, accurate object classification and precise content measurement are key factors in the implementation of the system [12].

The recognition of foreign fibers of targets is the key machine vision technology, in which image segmentation is an important step. Image segmentation is a process of partitioning an image into multiple regions and is typically used to locate objects and boundaries (lines, curves, etc.). The aim of image segmentation is to partition the image into meaningful connected components to extract the features of the objects [24]. The segmentation results are the foundation of all subsequent image analysis and understanding, such as object representation and description, feature measurement, object classification, and scene interpretation. Thus, image segmentation is very important in processing the image. The popular approaches for image segmentation are: histogram-based methods, edge-based methods, region-based methods, model based methods and watershed methods [6,23].

Fast and precise segmentation has always been of great concern to people. Various image segmentation methods are reported in the literature [2,11,15] some of which are used in the Automated Visual Inspection system in agriculture [3,7]. In recent years, researchers have developed more efficient, but also more complicated methods for segmentation. For example, Tseng and Lee [22] proposed a novel approach based on image blocking to binarizing document images, and the binarization method obtains the highest recognition accuracy than other existent approaches. Zhou et al. [9] proposed a bubble image adaptive segmentation method based on fuzzy c means (FCM) algorithm and watershed transform to extract a morphological feature froth image which is low in contrast and weak in froth edges. Kainuller et al. [10] used a statistical shaped model combined with a constrained free-form model to segment the kidney in images acquired by Computed Tomography (CT). Thomas and Michel [20] presented a new theoretical framework for multidimensional image processing using Clifford algebras to detect edges by computing the first fundamental form of a surface associated to an image. Michael Fried [8] presented an adaptive finite element algorithm for segmentation with denoising of multichannel images in two dimensions, of which an extension to three dimensional images is straight forward. Schmidt et al. [17] presented a system that allows defining a set of rules, based on which abdominal organs are segmented (including the liver) using simple functions (like region-growing, or morphological operators). Liapis et al. [13] proposed a wavelet-based algorithm for image segmentation based on color and texture properties. Bentrem [4] proposed a computational method

which efficiently segments digital grayscale images by directly applying the Q-state Ising (or Potts) model. Furukawa et al. [5] used a maximum posterior probability estimation for rough liver extraction subsequently refined with a level-set method. Seghers et al. [16] presented an active shaped model method, in which multiple local shaped models are used. Susomboon et al. [18] used intensity-based partition, texture-based classification, probability model, and thresholding to segment the liver. A. Bardera et al. [1] presented a novel information-theoretic approach for thresholding-based segmentation that uses the excess entropy to measure the structural information of a 2D or 3D image and to locate the optimal thresholds. Mohamed Benjelil et al. [14] proposed an accurate and suitably designed system which is based on steerable pyramid transform for complex document segmentation, and the method performs consistently well on large sets of complex document images.

Although the methods mentioned above may perform successfully in specific circumstances, they will possibly encounter difficulties in the process of segmenting cotton foreign images. Due to the diversity of thickness, colors and shapes of foreign fibers, the images of cotton foreign fibers possess features as followed: low image contrast ratio, inhomogeneous image gray level and small area ratio of the target image, which bring many difficulties to image segmentation. It is hard to attain a satisfying result by using the above image segmentation methods, or conventional image segmentation. Consequently, it is necessary to utilize the image pre-processing method to solve those problems. In the practice of image processing, image preprocessing refers to processing work in advance of the feature extraction, segmentation and matching of the image input. And the main aim of image preprocessing is to eliminate the irrelevant information in the original image, regain the valuable and authentic information, and strengthen the detestability of relevant information, as well as to simplify the date to the maximum, therefore to improve the reliability of feature extraction, segmentation, matching, and recognition. In another words, image preprocessing provides better information based images for the image segmentation and makes it easy to segment images. In this article, a novel method based on image preprocessing and adaptive thresholding method is proposed to segment such low-contrast images.

On the other hand, the ultimate purpose of the cotton foreign fiber inspection is to realize the classified recognition and calculation of cotton foreign fiber. But in the actual inspection process, the circumstance of fracture on the edge of every image occurs at a relatively high frequency, that is, a line of foreign fiber gets across two or more images, which have a great influence on the subsequent classified recognition and calculation in that we need to take certain measures to connect foreign fiber images to get an intact image after the segmentation.

In the present research, the problems mentioned above can be solved by the following procedures: In the first step, we transform the captured color images of foreign fiber into gray-scale images, and invert the gray-scale of the transformed images. In the second step, we divide the whole foreign fibers image into several blocks to adjust and improve the proportional relationship between the target image and

background. The third step is the pre-decision of each image block which identifies whether a certain image block contains foreign fibers or not. In the fourth step, we eliminate the background by applying the methods of image erosion and gray level correction to image blocks that may contain foreign fibers. In the fifth step, we strengthen by sections the image blocks whose backgrounds have been eliminated and segment them with OSTU method afterward. The last step is to compare the edges of the segmented image with those of its neighbor images, with whose results we connect the segmented image blocks.

2. Materials and methods

2.1. Materials preparation

The foreign fibers used in this research were collected from cotton mills including feathers, hair, hemp rope, plastic films, polypropylene twine, colored thread, cloth piece, etc. as shown in Fig. 1. Adequate pure lint with no foreign fibers was also prepared for making the lint layer. The experiment selected a sufficient amount of lint cotton which does not include foreign fibers.

2.2. Image acquisition

The image acquisition system has two cameras, two light sources, one shaft encoder, one synchronizing amplifier, two image acquisition boards and a computer, as shown in Fig. 2. Colorful images are captured by a Canadian DALSA high-speed 3CCD color line scan camera under high-brightness LED lightning. The typical foreign fibers are concluded from the research on China's textile enterprises. To make the experiment easier, the foreign-fiber samples were dropping onto the surface of the pure lint one by one while the lint was feeding into the opening machine. After the lint with foreign fibers was being opened, a continuous cotton layer is formed, 400 mm wide and 2 mm thick, Totally 40 color images with 4000×500 in resolution were then obtained.

By observing the images obtained, it was easy to find that the opened foreign fibers appeared in three typical forms, as shown in Fig. 3a-c, (1) sheet, such as plastic films and papers, (2) wirelike, such as hair and color thread, and (3) villiform, such as hemp rope and chemical fibers.

As the original color image is too large but the target image is small, if the original image is directly inserted, it will result in an unclear target image that is hard to recognize by reader. So original images in this paper are cut into target images

2.3. Image processing

The ultimate purpose of the cotton foreign fiber inspection is to realize the classified recognition and calculation, so the main task is to get the intact cotton foreign fiber target image and to promote the image processing speed. Thresholding is a traditional method, which is widely used due to its computational simplicity, high speed, and easy implementation.



Fig. 1 – Foreign fiber samples.

Ostu's method, as an adaptive threshold method to confirm the threshold value, possesses the advantages of simple algorithm, high speed, so on. Moreover, it makes the biggest segmentation. Between-group variance implies getting the slightest chance to make errors, which means the Ostu's method has the optimum segmentation threshold value so that the application of Ostu's method become widespread. But there are problems of two aspects existing in the image process: the first one is the features of cotton foreign fiber image, i.e., small area ratio of the target image, inhomogeneous image gray level and low image contrast ratio, which leads to the result that we cannot obtain the segmented image with high quality via the direct use of the OSTU method; the other one is the fractures on the edge of every foreign fiber target image or produced in the image processing, which results in infeasibility to get the intact foreign fiber target image. Consequently, we employ preprocessing such as image block, image pre-decision, image background extraction, image enhancement and segmentation, and image connection, to solve those problems. The entire process was shown in Fig. 4.

2.3.1. Image transformation

In order to realize on-line processing of cotton foreign fiber with a high requirement of speed, we need to obtain satisfying image processing resulting in a very short time. The color image contains the data information of three channels, the processing speed of which is much slower than the gray-scale image. In addition, ordinary cotton foreign fiber images may need various segment models to process target images of different colors. Under this circumstance, in order to promote the processing speed, we transform the captured color images of foreign fiber into gray-scale images in this step. Then we invert the gray-scale of the transformed images to make subsequent processing easier.

2.3.2. Image blocking

In every foreign fiber image, the area of foreign fiber image that we are truly interested in is very small. Thus processing every whole foreign fiber image will not only influence the accuracy of segmentation, but also cost plenty of unnecessary time to deal with the background image, in other words,

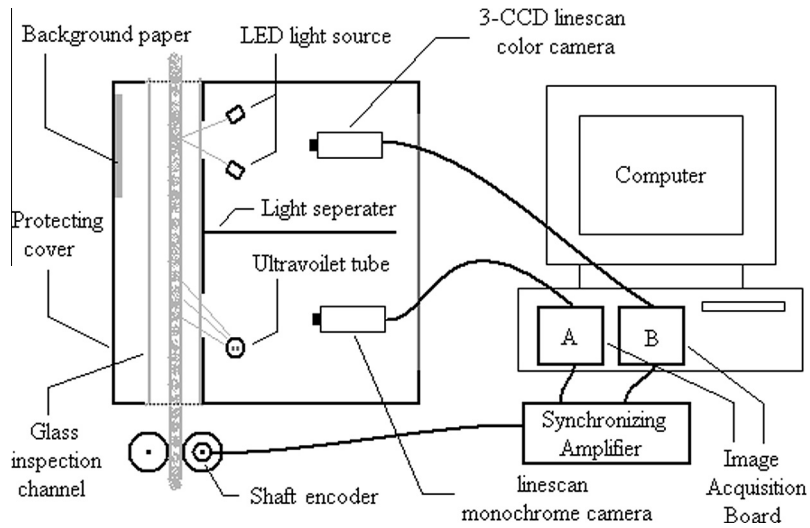


Fig. 2 – The image acquisition system.



Fig. 3 – Acquired color image examples: (a) opened chicken feather, (b) opened hair, and (c) opened black fiber cloth.

reduce the speed of image processing. Therefore, we employ the method of image blocking, which means that we divide the whole image into several image blocks to process and make pre-judgment in advance to extract the image block that does not contain foreign fibers. The advantages of the above method are threefold, i.e., promoting the ratio relation between target image and background image, time saving, and enhancing the accuracy and speed of the image segmentation. In this paper, the foreign fiber image is divided into eight on average.

2.3.3. Image pre-decision

As mentioned above, the amount of foreign fibers contained in the cotton of our nation is very small, so that the area ratio of foreign fiber target image to the intact image is small. Only a small part of the image we collect contains the foreign fibers, among which an even smaller amount can be used as foreign fiber target image after segmentation. In conclusion, the actual target foreign fiber image that we are truly interested in occupies a very small portion of all the image blocks we get from the segmentation. So it is essential for us to establish a image pre-judgment mechanism to see if there is a possible existence of a foreign fiber target image thus

we can make further disposition of the target image while rejecting the unnecessary part of the image, which will save much time.

The concrete method employed in this paper is shown in Fig 5, binarizationally segmented every image block with a proper threshold value M , and then computed the area of target image inside the binarizational image; if the area is less than the fixed value $A1$, then there is no need for further processing; if the area is larger than the other fixed threshold value $A2$, then further image processing will be in demand; if the area is between $A1$ and $A2$ we need to inspect whether there is a adjacent image block that has the image area larger than $A2$, and if there is such a image block then further processing is needed, otherwise it is not.

There is also another point needed to be illustrated that the segmentation threshold value M , area threshold value $A1$ and $A2$ are related to each other, and they are fixed based on plenty of experiments. These three values of the threshold value are comparatively small in their respective category so as to avoid mistakenly subtracting the target image block containing foreign fiber. Although doing so may lead to mistakenly treating the image block without foreign fiber as the target image to go in to the next step, and hence influences

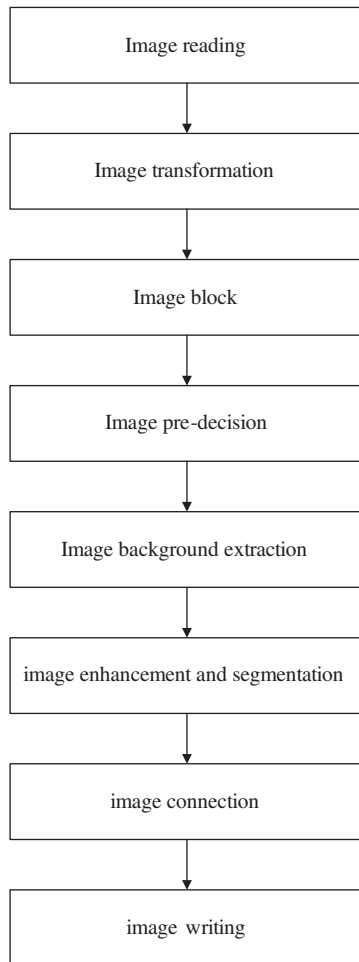


Fig. 4 – Flowchart of the image processing.

the subsequent imaging process. The threshold value is set as 72.65, and area threshold values A_1 and A_2 are, respectively, 80 and 125 through plenty of experiments.

2.3.4. Image background subtraction

As previously stated, owing to the features of the foreign fiber image, namely, low contrast ratio, lack of apparent difference between the object and background, heterogeneousness of the gray rate of background because of the uneven thickness of the layers of cotton, together with the unsatisfying segmentation effects of Otsu's method on the low-ratio image or heterogeneous gray rate image, we need to employ the method of background subtraction to enhance the contrast ratio and to promote the heterogeneous image background thereby getting a qualified segmentation effect.

Background subtraction is, by a variety of methods, getting the image background without the object, then subtracting from the original image so as to reach the aim to highlight the object and reduce the influence of the image background.

In the process of background subtraction, the first thing is to get the background image of the cotton foreign fiber image. In our research, we utilize the approach of a positive combination of image corrosion and gray-scale correction to acquire the background of cotton foreign fiber image.

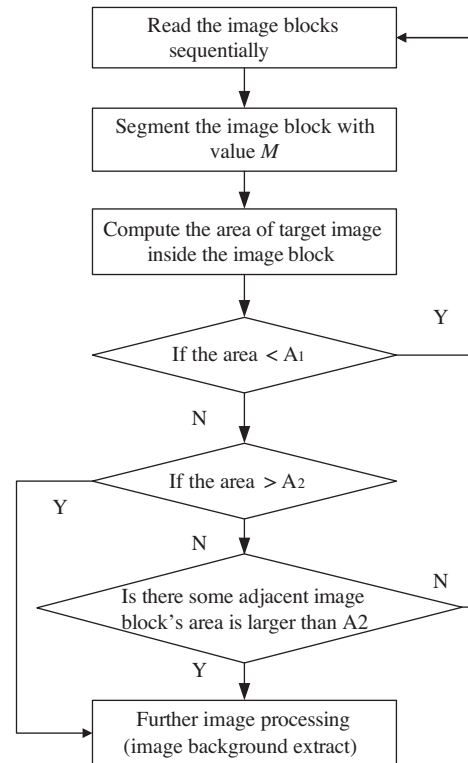


Fig. 5 – Flowchart of the image pre-decision.

Image corrosion is an image processing method in the area of mathematical morphology. Mathematical morphology is a mathematical tool which is based on morphological image analysis, also called image algebra. It is a subject built on the basis of rigorous mathematical theory, and the image processing is based on geometry. The basic principle of mathematical morphology is to regard the binary image as the set, and to use structural elements to search. The structural element is a key concept in morphology.

Let $f(x, y)$ be the image intensity function, $g(i, j)$ be the gradation function for the structural element. The definition of image corrosion for gradation function $f(x, y)$ is:

$$f \ominus g(x, y) = \min_{(i,j)} \{f(x+i, y+j) - g(i, j)\} \quad (1)$$

gray scale correction refers to the operation as replacement, amplification or contraction of the gray-scale value of some relevant or featured pixels to obtain the required effect.

The foreign fibers in cotton are majorly from three categories wirelike, villiform, and sheet. For the foreign fibers of the former two categories, we can apply the method of image corrosion to get their background image. Since the area of the foreign fiber target image in the shape of a sheet is so large the image corrosion method may lead to target image remnants. And the heterogeneous effect of the gray rate cannot be eliminated by excessive argumentation of structural elements but lower the quality of the background image instead. We could find, through the image feature analysis, that sheet shape foreign fiber target image possesses the feature of a large difference between the target image gray rate and background, thus we can amend this type of image by the method of gray rate revision, i.e., the revision of pixels' gray rate in the

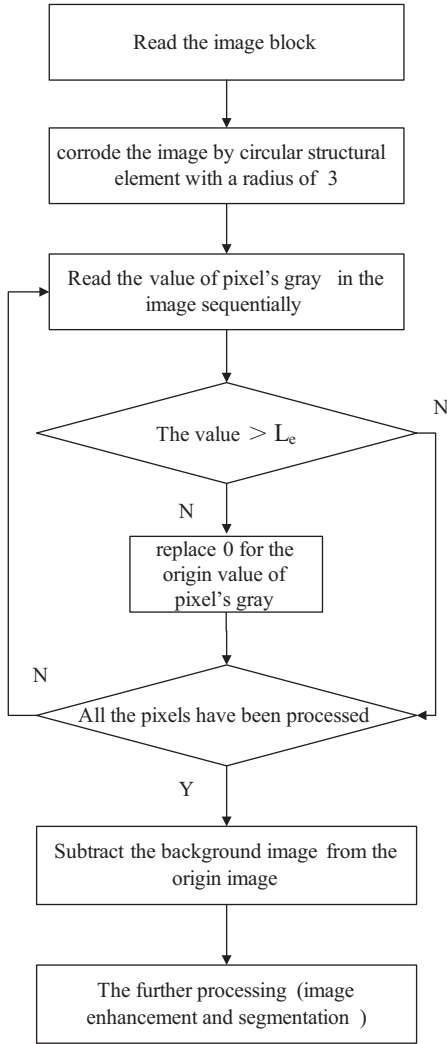


Fig. 6 – Flowchart of the image background subtraction.

certain set region of the image. Therefore, we utilize the approach of a positive combination of image corrosion and gray rate revision to eliminate the background of cotton foreign fiber images. The concrete procedures are shown in Fig. 6: the image is corroded by a circular structural element with a radius of 3, and the pixels that are larger than 0.6 are revised

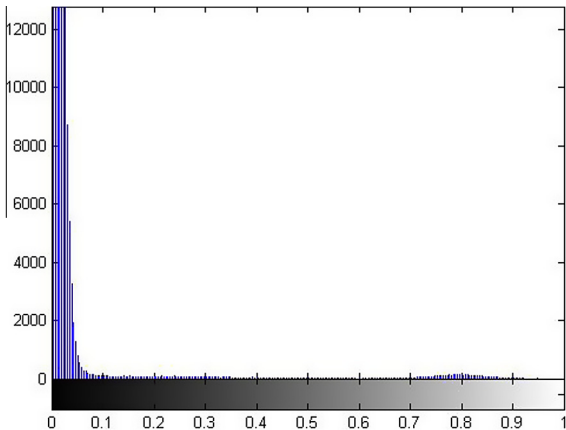


Fig. 7 – Histograms of hair image.

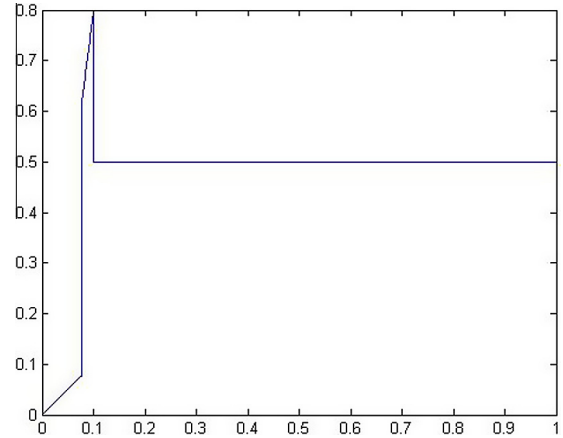


Fig. 8 – Line of three-piece linear enhancement model.

after corrosion to make it convenient for us to replace 0 for the original value of pixel's gray rate so as to get a background image with higher quality. Thereby, the option of structural element and revised value of gray rate are determined by experiments.

2.3.5. Image enhancement and segmentation

Then we analyze, by histogram, the image after elimination of the background as shown in Fig. 7, from which we could discover that the gray rate is rather converging and the contrast ratio is also very low. Most pixels with gray rate values below 0.08 belong to the background figure, whereas pixels with a gray-level value above 0.1 belong to other parts of the foreign figure image. And the pixels whose gray-level values are among 0.08–0.1 belong to the co-existing part of background and foreign fiber, that is, the gray edge of the object and background, which exerts the most significant influences on subsequent image segmentation. To enhance the contrast of the image, it is necessary to resort to a piece wise linear transform model, which could promote the contrast remarkably especially in the range from 0.08 to 0.1. A piecewise transform model splits the distribution range of image pixels into two or more pieces, and performs a transformation to each piece, respectively, to enhance the region of interest. The main objective of our research is the foreign fiber segment form of the background image, so a three-piece nonlinear model was proposed and described as follows.

Denote the original gray level in image position (i,j) to be $GO(i,j)$, and the corresponding enhanced gray level to be $GE(i,j)$. The gray-scale range needed to focus on the image enhancement is $[L_l, L_h]$. The three-piece linear transform model for image enhancement is defined as

$$GE(i,j) = \begin{cases} GO(i,j) & GO(i,j) \leq L_l \\ 8 * GO(i,j) & L_l < GO(i,j) < L_h \\ 0.5 & L_h \leq GO(i,j) \end{cases} \quad (2)$$

According to the histogram analysis, we set $L_l = 0.078$ and $L_h = 0.1$. The line of this three-piece enhancement model is shown in Fig. 8.

After the image enhancement, we analyze the enhanced image gray rate, in whose histogram, there is an obvious improvement in the contrast ratio of the enhanced image,

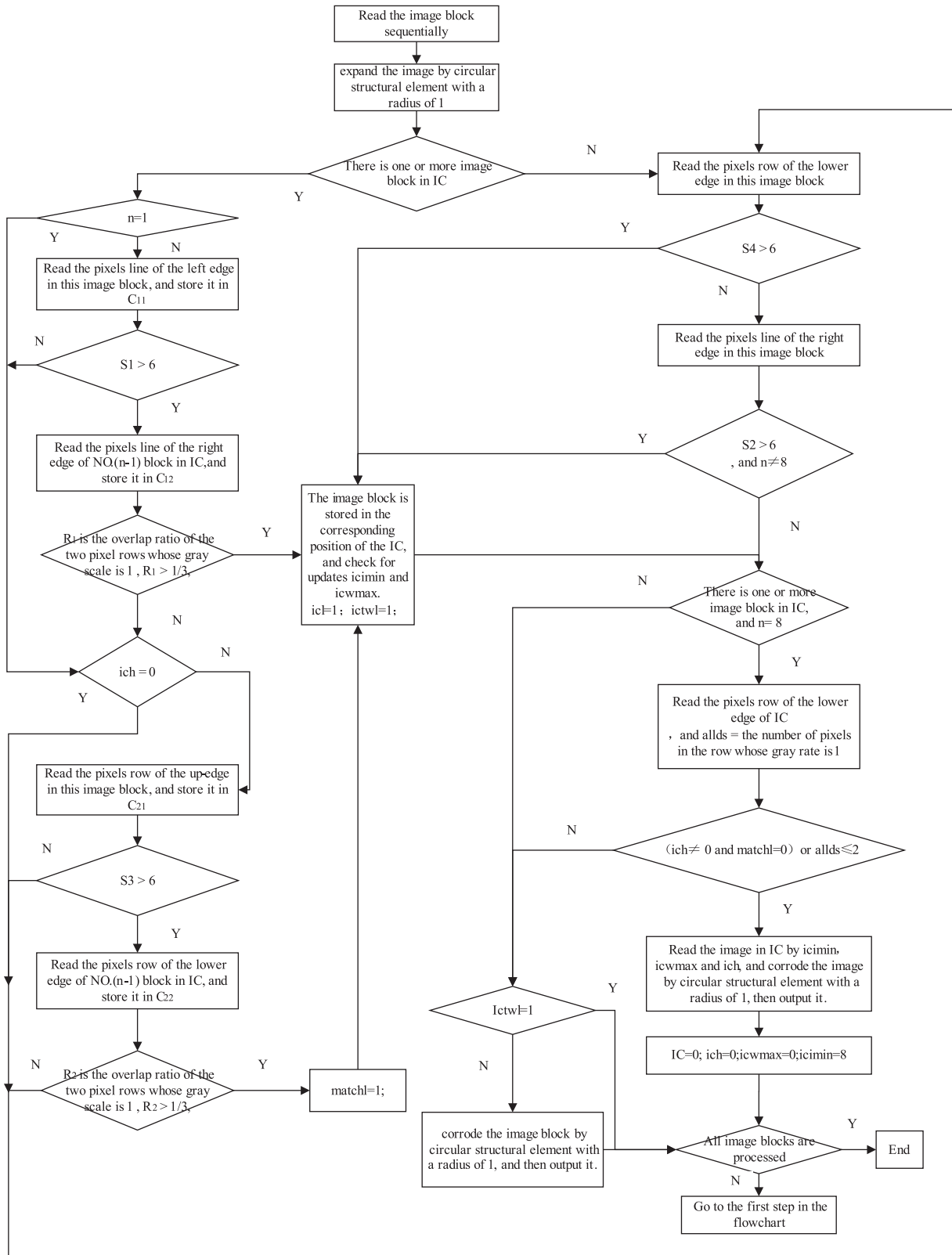


Fig. 9 – Flowchart of the image connection.

and the gray rate difference is also very clear, offering ample preparation for subsequent image segmentation. Thereafter, we can segment the enhanced foreign fiber image with the OSTU method.

2.3.6. Image connection

The ultimate goal of cotton foreign fiber online inspection is to realize the classified recognition and computation of the cotton foreign fiber, the pre-requisite condition is to obtain

the intact and distinct target image of the cotton foreign fiber, i.e., the major problem in this paper. However, there exist quite a lot of fractures of the target image after a series of image processing procedures mentioned above. And the reasons for these fractures are from two aspects: first, two parts of target foreign fiber image, respectively, in two neighboring image blocks, thus producing fractures; on the other hand, the target foreign fiber appears accidentally on the edge of image block, or in other words, it crosses several image blocks, and the fractures are thereby produced. So we need to connect effectively the target images that have fractures in order to get intact and distinct cotton foreign fiber target images.

The method for target image fracture connection employed in this paper contains four steps as follows: Step 1. Expand the segmented image blocks with a proper structural element; Step 2. Load in sequence the 4 lines (rows) of edge pixels of image blocks and judge whether the image blocks

contains foreign fibers or not; Step 3. Compare the pixel lines that contains target image with their corresponding pixel lines (rows), and by comparing the overlap ratio of the two pixel lines (rows) whose gray rate is 1 is larger $1/3$, we could connect the image block; Step 4. We output the whole image block that has already been connected thereby getting the intact foreign fiber target image.

The notes of the symbolic values used in Fig. 9 is as follows: we know from the introduction above of the algorithm, that the whole foreign fiber image has been divided horizontally into eight equal blocks. We number them 1–8, respectively, and represent them by “ n ”. IC represents for matrix of $4000 * 4000$, which is used to store the image blocks that need to be connected. I_{min} stands for the minimum No. of image blocks stored in the matrix, whereas I_{max} stands for the maximum No. of image blocks stored in IC. I_{ch} stands for the amount of image blocks. And “mactchl” is the mark of the matching of the image blocks. Let $P(x, y)$ denote the gray-

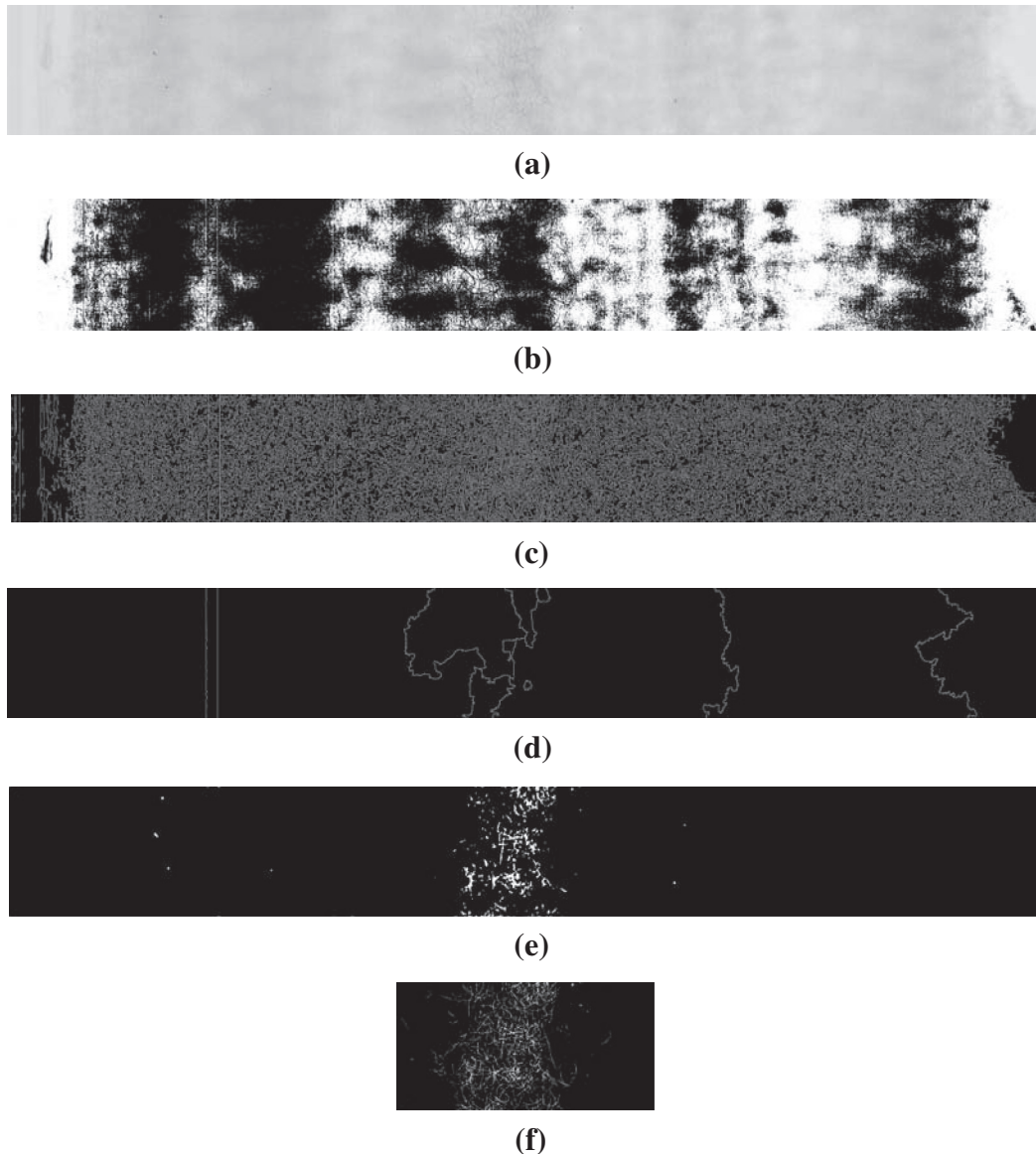


Fig. 10 – (a) Original image of hemp rope, (b) Ostu's algorithm, (c) Canny algorithm, (d) the conventional watershed algorithms, (e) Zhang's algorithms, and (f) algorithm of this paper.

scale of the pixel whose coordinates are (x, y) in the image block, h, w denote the height and width of image blocks, respectively, $S1, S2, S3, S4$ stand for the number of pixels lines or rows, whose gray rate is 1, defined as follows:

$$S1 = \sum_{y=1}^h P(1, y) \quad S2 = \sum_{y=1}^h P(w, y) \quad S3 = \sum_{x=1}^w P(x, 1) \quad S4 = \sum_{x=1}^w P(x, h) \quad (3)$$

The $addls$ stands for the number of pixel lines on the bottom of image in IC. Let $Pg(x, y)$ denote the gray-scale of the pixel whose coordinate is (x, y) in IC, the $addls$ is defined as:

$$addls = \sum_{x=1}^{w+n} Pg(x, (ich * h + 1)) \quad (4)$$

The C_{ij} is a pixel line or row which is read, let I denote the image block being processed, $i, j = 1, 2$, C_{ij} is defined as follows:

$$\begin{aligned} C_{11}(1, y) &= P(1, y), \\ C_{12}(1, y) &= Pg((500 * (n - 1) + 1), (y + ich * h)), \quad y = 1 : 500 \\ C_{21}(x, 1) &= P(x, 1), \\ C_{22}(x, 1) &= Pg((500 * (n - 1) + x), ich * h) \quad x = 1 : 500 \end{aligned} \quad (5)$$

R_i stands for the overlap ratio of the two pixel lines or rows whose gray scale is 1, $i = 1, 2$, it is defined as:

$$\begin{aligned} R_1 &= \frac{\sum_{x=1}^w C_{11}(1, y) + \sum_{x=1}^w C_{12}(1, y) - \sum_{x=1}^w (C_{11}(1, y) - C_{12}(1, y))^2}{\sum_{x=1}^w C_{11}(1, y) + \sum_{x=1}^w C_{12}(1, y)} \\ &= \frac{\sum_{x=1}^w C_{21}(x, 1) + \sum_{x=1}^w C_{22}(x, 1) - \sum_{x=1}^w (C_{21}(x, 1) - C_{22}(x, 1))^2}{\sum_{x=1}^w C_{21}(x, 1) + \sum_{x=1}^w C_{22}(x, 1)} \end{aligned} \quad (6)$$

There are several points that need to be illustrated in connection with the method mentioned above: (1) in step 1, the structural element employed in image expansion is a kind of circular structural element with a radius of 1; (2) in step 2, the way of judging whether pixel lines (rows) have a foreign fiber image is to identify if the number of pixels, whose gray rate is 1, is larger than P ; in step 3, the method for image block connection is to establish a blank matrix IC with the same width for every frame of the image which is capable of keeping the N flames of the cotton foreign fiber image, and thereafter to put image block which needs to be connected in the corresponding place, and record the position deposit of the image block in IC, then make an integrated output of image blocks in the recorded position; in step 4, after we finish processing all the image blocks in every flame of image, there we confront two possible situations than can be judged as the connection is finished, of which the first one is that is pixel lines at the bottom of the image in IC do not contain any foreign fibers, the second one is that there is no image block in the just connected image flame linked with the image block of other image block.

3. Results and discussion

There are seven typical foreign fibers that have been used in the experiments, i.e., plastic film, feather, polypropylene twine, hair, color thread, hemp rope, and cloth piece, and ten samples of each type had been prepared. That is to say,

there are 70 foreign-fiber samples altogether. In addition, ample amount of pure lint without foreign fibers has also been prepared to make the lint layer. In our experiments, the pure lint with one type of foreign fiber dropped onto the surface at each time interval was first fed into the opening machine and made into uniform thin layer with a width of 400 mm and a thickness of 2 mm. The foreign fibers in the lint layer were presented in three forms, namely sheet, wirelike, and villiform.

All the results of this paper were processed by the computer with the programing tools developed in Matlab7.0. Operating environment consists of: Inter Core2. PC-frequency: 2.60 GHz, 2G Memory. And Windows XP was selected as the operation system.

3.1. Analysis of image segmentation results

In the paper "A Fast Segmentation Method for High-resolution Color Images of Cotton Foreign Fibers" ([24]), the author presents a fast approach for segmenting images of foreign fibers in cotton. Firstly, color images were captured, and the edges of color images were detected by the edge detection method which is based on improved mathematical morphology. Then the color images were converted into a gradient map, the law of experience values was analyzed, and the best thresholding of the gradient map was chosen by selecting the best experience value iteratively. The proposed method can segment the high-resolution color images of cotton foreign fibers directly and precisely, and the speed of image processing is more than double that of the traditional methods (referred to as Zhang's algorithms hereinafter).

In our research, more than 2500 sample images were tested and compared using the Otsu's algorithm, Canny's algorithm, the conventional watershed algorithm and Zhang's algorithm. The image segmentation results were shown in Fig. 10.

It is safe for us to come to the conclusion that the direct use of Otsu, Canny, and the conventional watershed algorithms to segment images cannot get a clear segmentation of the object figure which is desired by us. While Zhang's algorithms could get better segmentation results, the algorithm of this paper contains more foreign fiber image details that provide a much clearer segmentation results and higher segmentation accuracy. What should be noted here is that Fig. 10 shows the segmentation result of a single flame of the cotton foreign fiber image so that we can have a clear comparison with other algorithms. As mentioned in the previous paper, the algorithm also possesses the function of image connection. In the actual experiment, we process continuous flames of images therefore we could get intact and clear target images, while other methods do not have this function, as shown in Fig. 11.

3.2. Analysis of image calculating speed

We have made a comparison, during the image segmentation experiments, of the calculating speed of five methods, namely, Canny algorithms, the conventional watershed algorithms, Zhang's algorithms, and the algorithm of this paper. Then we arrive at the result that the average time for the four

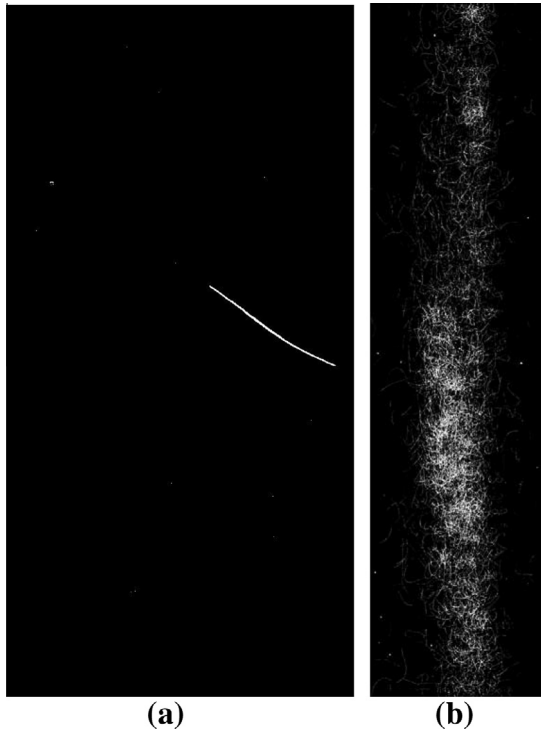


Fig. 11 – (a) Connected hair image and (b) connected image of black fiber cloth.

kinds of segmentation methods of processing foreign fibers are: 3.65, 9.11, 3.56, and 1.72 s. Table 1 shows the average time of the five kinds of segmentation algorithm.

We can see from the results shown in Table 1 that, the other three algorithms' calculation speeds are apparently slower than the one presented in this paper. Moreover, this algorithm has great advantages over other algorithms in segmentation accuracy according to the segmentation result. Fast as it may be, exclusively using the Ostu algorithm without any pre-processing of image segmentation could not provide the expected result for us.

On the other hand, the algorithm also has the advantage of speed. Since the quantity of foreign fibers contained in cotton is very limited, most parts of the image do not contain any foreign fibers, which we called pure cotton. The traditional algorithm and Zhang's algorithm make no difference in image processing of both the foreign fiber image and pure cotton image. It means that they are comparatively time-consuming and to a similar extent, also easily bring mistakes, which incur difficulties in image processing. The phase of image blocking and pre-decision in the algorithm put forward in the present study will save much time in that it skips some sub-

sequent unnecessary processing steps. The experiments show that the algorithm in the present research costs about 0.61 s in processing a pure cotton image, showing that this algorithm has made a great advancement in the aspect of processing speed, especially in the condition that the majority of the images we get are pure cotton images.

Thus, the results of above analysis showed that we can acquire better segmentation results with faster speed, whether in the case of wirelike, villiform or sheet foreign fibers.

3.3. Analysis of image blocking

We choose the OSTU method which has a simple algorithm, high speed and spread feasibility to segment the image. However, it is manifested in the result of segmentation under the Otsu's method that the segmentation is approximated to the optimum in the condition that the object figure is larger than 25% of the whole image; and the property of algorithm will decline rapidly in pace with the decrease of the area of moving object figure, resulting in smaller object figure and larger threshold value variance. Whereas, while analyzing the foreign fiber image which is 4000 * 500 larger in size, we find that the object figure occupies only 5% or even less of the whole image. Most parts of the foreign fiber object figure occupies 0.5-3% of the whole image. In order to increase the ratio of object figure and the background, we horizontally divide the original foreign fiber image into eight equal parts, each 500 * 500. And the experiments prove that it is an apt choice to divide the whole flame of cotton foreign fiber image into eight blocks. If the number of image blocks is too large, we cannot effectively improve the ratio relation of the target image and background. And on the contrary, if the number of sub-blocks is too small, a circumstance in which some specific target image occupies most of the area of the image block, which may exert unfavorable effects on the accuracy of the segmentation, while costing more time for subsequent image correction.

3.4. Analysis of image pre-decision

We have discussed in the previous passage that both the containment of foreign fibers in cotton and the area the foreign fibers target image occupies are very small. So only a small part of the image contains the target image. Consequently, we make a pre-judgment of the obtained image block and then process the image block containing the target image after eliminating most of the image block without the target image, thereby promoting the processing speed of image processing.

In the pre-judgment method used in this paper, the threshold value M , area threshold values $A1$ and $A2$ are related based on the judgment results of numerous experiments. For example, if we set M at a smaller value, then there will be more parts of the image segmented as target image. And we need to tune $A1$ and $A2$ to a large value. In the experiment, to ensure that the image block containing a foreign fiber target image would not be erroneously judged as the target image and then eliminated, we fix the three threshold values

Table 1 – Comparison of experiment results.				
Time (s)	Segmentation method			
	Canny	Watershed	Zhang's	This paper
Average time of calculation	3.65	9.11	3.56	1.72

with small values. Owing to the different factors such as thickness of different cotton layers and illumination intensity, the gray rate of the foreign fiber image background is rather heterogeneous, and some of the cotton background in the image has a deep color close to that of the foreign fiber target image. So some of the cotton background with deep color may also be mistakenly judged as foreign fiber target images and then processed into the next step, but this kind of image exerts a slight influence on the classified recognition and computation.

On the other hand, the setting of the area threshold value $A1$ and $A2$ is of great importance. If the value is too large, it may cause many image blocks containing the target image to be misjudged as the image block without the target image so that the intact target image cannot be obtained. If the value is too small, it may cause the misjudgment of many image blocks without target images as the target images, influencing the image processing speed. Therefore the method explained in this paper which involves two area threshold values $A1$ and $A2$ categorize the image blocks into sub-categories, and process and judge them, respectively, in accordance with their relative positions. This method has the advantages of better adaptability and accuracy for image judging, and higher image processing speed. Furthermore, this method can also solve with the guarantee of judgment accuracy the problem of two misjudgments: (1) some foreign fibers produce fractures on positions close to the edge, then only a small part of the foreign fibers target image occurs on one image block while the neighboring image block contains a larger part of the target image. In this situation, the image block with a smaller part of foreign fibers may be judged as not having any target image, so as to lead to the incompleteness of the foreign fiber target image. (2) Except foreign fibers, cotton usually also contains fake foreign fibers such as cotton seed, grandiflorum, cotton leaves, and so on, which are apparently deeper than the background image gray rate but occupies a smaller area than the foreign fiber target image. They are not the focus we are interested in, but lead to misjudgment of the image block having the faked foreign fibers as the image block having foreign fiber target images.

From the statement above, there are two aspects behind the misjudgment: (1) some parts of high gray-scale of background image are misjudged as foreign fibers; (2) fake foreign fibers existing in the image block are mistakenly treated as foreign fibers. Therefore, two, respectively, corresponding solutions to reduce the misjudging rate are as follows: (1) increase in the threshold value M in a reasonable range; (2) enlargement of the disparity between fake foreign fibers and foreign fibers by the binaryzation of the image block by the threshold value M . By analyzing the gray-scale of the image we find that the gray-scale of background image of the image block ranges from 20 to 75. And some of the foreign fibers target image's gray level approximates to that of the background image, such as hemp rope with a gray-scale between 65 and 155. Thus we need to fix the threshold value M in the scope of 65–75. The analysis of image area indicates that the area values of foreign fibers in the image block falls in the scope of 25–150, most of which are lower than 120. In order to bring down the misjudging rate of the pre-decision system, we need to find a proper threshold value M to assure that

the areas of foreign fiber target images after binaryzation are greater than 120, which is the prerequisite condition for us to increase M to the greatest extent. Consequently, we binarize all foreign fiber target image blocks with different set threshold value M , and document all the area values of target images in the image block. The scope of threshold value M is 65–75, with a step size of 0.05. The experimental results manifest that the area values of the target image reduce gradually along with the increase of the threshold value M . As the threshold value is set as 72.65, 98.2% of all the image blocks after binaryzation by M has area values greater than 120, and all these image blocks' area values are above 80. We set the area threshold value $A1$, $A2$ as 80, 125, respectively, so as to correctly judge all the image blocks that contain foreign fibers, namely, to reduce the rate of misjudging fake foreign fibers as foreign fibers. On the other hand, background image with the gray-scale higher than 72.65 occupies only 0.62% of the total image blocks, which greatly reduces the rate of misjudging the high gray-scale background images of the foreign fiber. So, it can maximally reduce the system misjudging rate on the condition of ascertaining that all the foreign fibers can be correctly judged for us to set the threshold value M , area threshold $A1$, $A2$, respectively, as 72.65, 80 and 125.

3.5. Analysis of image segmentation

From the segmentation result we can see that the optimum threshold values gained from applying the OSTU method toward the strengthened image intensely converge around 113, and some threshold values use 113 as their true value. Therefore, we carry out another experiment in which we use the fixed threshold value to segment the image instead of the OSTU method. The result of the experiment manifests that most parts of the foreign fiber target images can be segmented satisfyingly. The reason for this is that after image division into blocks and background elimination, the contrast ratio of image and homogeneity has been obviously improved whereas the image strengthening model established in the paper enhances critical detailed parts of the image block by a large margin, consequently roughly separating the target image and background in the strengthened image block so as to make the obtained optimum threshold value highly centralized. Although the method using a fixed threshold value can increase to a certain extent the image processing speed, it will reduce the adaptability of the algorithm so that we cannot get image processing results with high quality. On that basis, we come up with a simple way to improve it: segment the first flame of the image by the optimum threshold by OSTU, then segment subsequent images with the fixed threshold value. Henceforth, we can gain the optimum threshold value by the OSTU method every 30 flames of the image, with which we can replace the former threshold value to segment the subsequent images. Otherwise we can adopt a comparatively simple mechanism to inspect the segmented images, and use the optimum threshold value gained by the OSTU method to segment subsequent images when something in the results of the segment goes wrong. This could promote the speed to a certain extent while ensuring adaptability of the algorithm.

4. Conclusion

We choose the OSTU method, which is simpler and faster, to segment images, but the Ostu algorithm has problems in segmenting the image that has low contrast ratio between object figure and background, small area of object figure or heterogeneous gray-level of background image—of which type the foreign fiber image unfortunately belongs to, we seek for a solution by a series of pre-processing methods such as image block, background subtraction, and gray balance, in order to promote the segmentation accuracy. At the same time, we also establish the image pre-judgment mechanism to increase the image segmentation speed and connect the target image that produce fractures therefore obtaining intact and clear foreign fiber target images.

The experimental result demonstrates that the algorithm of this paper has great advantages over other algorithms in the past both in the aspects of accuracy and speed. The mandate of speed is a key factor for the online visual inspection system. Hence, in addition to ensuring the segmentation accuracy, algorithms of faster speed are now being studied.

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