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Measuring the Geometrical Parameters of Slub Yarn Using a Computer Vision Based Image Sequencing Technique

DOI: 10.5604/01.3001.0013.0739

Abstract
This article presents a computer vision method for measuring the geometrical parameters of slub yarn based on yarn sequence images captured from a moving slub yarn. An image segmentation method proposed by our earlier work was applied to segment sequence slub yarn images to obtain overlapping diameter data. Then an image stitching method was proposed to remove the overlapped data based on the normalised cross correlation (NCC) method. In order to detect the geometrical parameters of slub yarn, the frequency histogram, curve fitting , and spectrogram methods were adopted to analyse the sequence diameter data obtained. Four kinds of slub yarn with different geometrical parameters were tested using the method proposed and Uster method. The experimental results show that the detection results for slub amplitude, slub length, slub distance, and slub period obtained using the method proposed were consistent with the set values and Uster results.

Key words: *slub yarn sequence image, geometrical parameter measurement, image segmentation, image stitching.*

Introduction

Slub yarn is a simple fancy yarn whose appearance is gained by the variation of yarn linear density during the spinning process [1]. It can be produced by modifying the ring spinning frame because the intermittent acceleration of the rollers causes varying degrees of draft [2]. This special appearance is determined by the different geometrical parameters of slub yarn, including slub amplitude, slub length, slub distance, and the periodicity rule of the slub. These parameters can make woven fabrics have special aesthetic properties [3, 4]. Therefore detecting the geometrical parameters of slub yarn is extremely significant for designing the aesthetic properties of fabric [5].

The traditional method for analysing the geometrical parameters of slub-yarn is to count slubs in the yarn based on the black boards, which demands special experience from workers. However, this method cannot get enough length of slub yarn to detect the geometrical parameters because the slub has no repeat in a short length [6]. The method is also very tedious and time-consuming.

In recent years, many methods for measuring slub geometrical parameters automatically have been reported. The principles of measuring slub geometrical parameters can be classified into three main categories, which are summarised with their pros and cons in ***Table 1***. These methods are as follows: combining a capacitance-type sensor with the voltage signals method [5, 7-9]. This method acquires mass data of slub yarn using a capacitance-type sensor first. And then the data are expressed as voltage signals through a digital storage oscilloscope or data acquisition card (DAQ) etc. The Uster Tester is usually utilised in this method. However, using a capacitance-type sensor to obtain the slub yarn diameter is an indirect method of detecting slub geometrical parameters. The detection result of slub yarn shows a big difference from that with the traditional visual method. The result of this indirect method also depends on the test environment conditions because the capacitors are usually affected by the temperature and humidity. The resolution of this method is relatively low, where the capacitors sample data every 8 mm (e.g. old versions of the Uster tester) [10].

The Constant Tension Transport (CTT) Tester method [11] was developed by the Lawson and Hemphill Company. In the tester, a Charged Coupled Device (CCD) array is used to collect yarn profile or diameter data as the slub yarn moves through the tester. And then an Oscilloscope and the threshold value are utilised to transform the data into a voltage signal. Although this method is not affected by the test humidity or fibre blend variation, it might be by the presence of lint and yarn hairiness.

The second is the image analysis method [6, 12], where the slub yarn is usually wrapped on a black board. And then a camera, flat scanner, etc. is adopted to capture the slub yarn image. Next image segmentation methods, which consist of the threshold , Gabor Filter and morphological algorithm methods, are applied to obtain the diameter data. Finally the data are processed using the Histogram method, Cluster method, etc. However, a fast device for obtaining a slub yarn image continuously has not been presented thus far. And an accurate image processing method has also not beenproposed to detect the geometrical parameters of slub yarn from yarn sequence images.

Table 1. *Advantages and disadvantages of the methods for measuring the geometrical parameters of slub yarn.*

Methods	Advantages	Disadvantages
Capacitance-type sensor with voltage signals method	– Primitive and dominant method – Fast	– Depends on the testing environment – Indirect method – Low resolution
CTT Tester method	– Does not depend on testing environment – High resolution	– Affected by the presence of lint and yarn hairiness – Yarn under tension reduces the diameter measured
Image analysis method	– Pixel-level resolution – Not affected by yarn hairiness – More accurate	– No detection instrument is formed

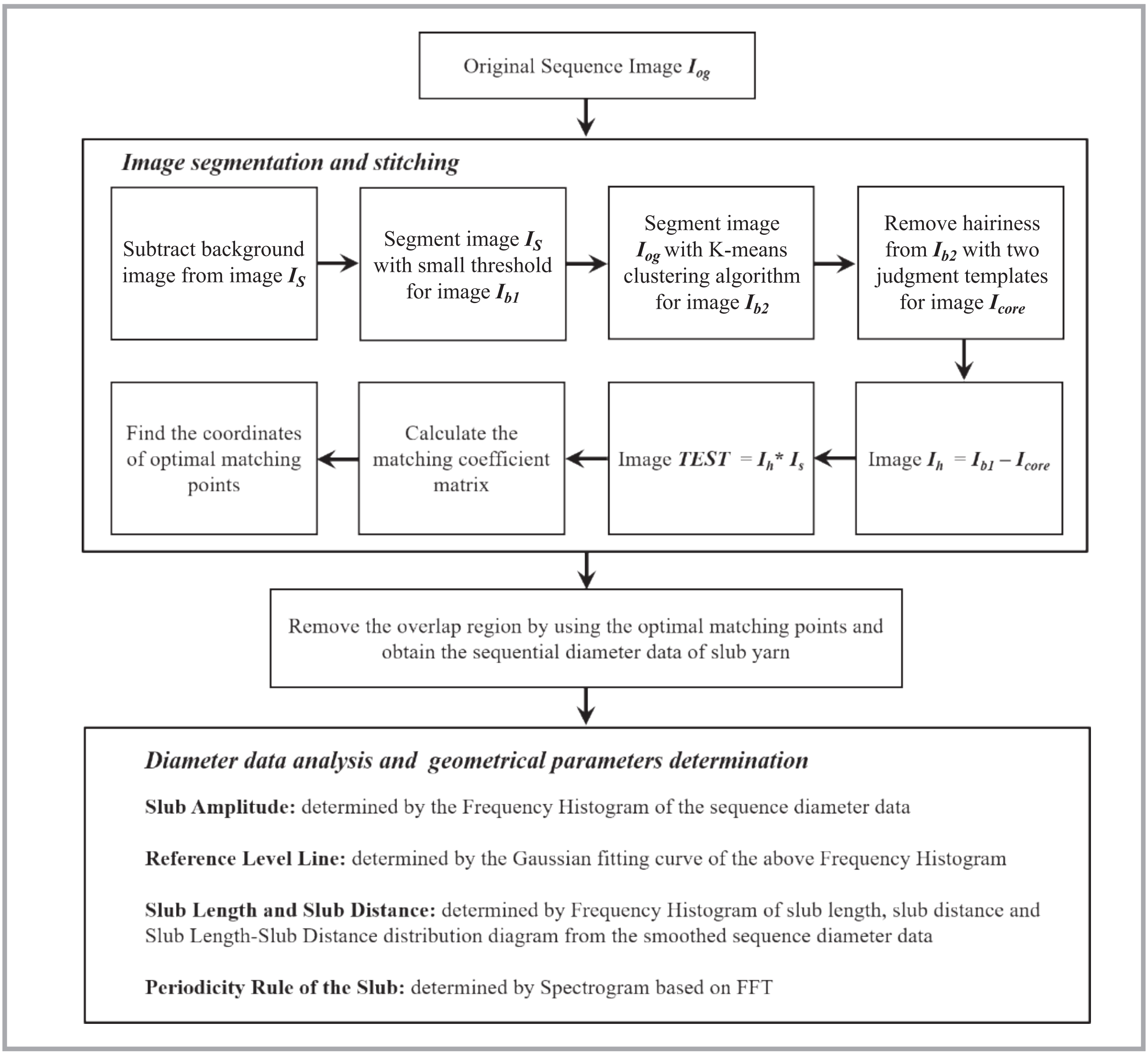

Figure 1. *Flowchart of inspection process.*

This work aims at tackling the problems of the image analysis method and presents a computer vision method to measure the geometrical parameters from slub yarn sequence images. In our earlier work [13], a novel method for measuring the unevenness of the yarn apparent diameter based on yarn sequence images had been proposed. In this method, the *K*-means clustering algorithm was employed to classify the pixels of each frame in the sequence into two clusters – yarn and background. Then the yarn core was further extracted utilising the characteristics of yarn hairiness from the classified image, and two judgment templates were adopted to remove burrs, isolated points and unrelated small areas in the images. In that experiment, four kinds of yarns were tested using this method and an Uster Evenness Tester 5. The experimental results showed that the method proposed could accurately detect the unevenness of the yarn apparent diameter, consisting of short-term, long-term, and periodic variations.

In this study, an image acquisition device was used to capture the overlapped slub yarn sequence images. Then the segmentation method proposed by our earlier work was applied to segment the overlapped sequence images and an image stitching method proposed to remove the overlapping area based on the normalised cross correlation method. Subsequently sequence diameter data were obtained.

In order to calculate the slub amplitude of each sample, a frequency histogram of the sequence diameter data is first constructed. And then the Gaussian distribution functions of each frequency histogram are fitted. Finally the slub amplitude and reference level line value are calculated using the coordinate values of two wave crests and the cross point of two fitting functions, respectively.

In order to measure the slub length and slub distance, the sequence diameter data are smoothed first. Then the smoothed data are separated into 0 and 1 signals by means of the reference level line value obtained. Next the number of consecutive 1 and 0 data is counted, and suspect data are removed or combined by means of two judging conditions. Finally the slub length and slub distance are measured from the slub length histogram, slub

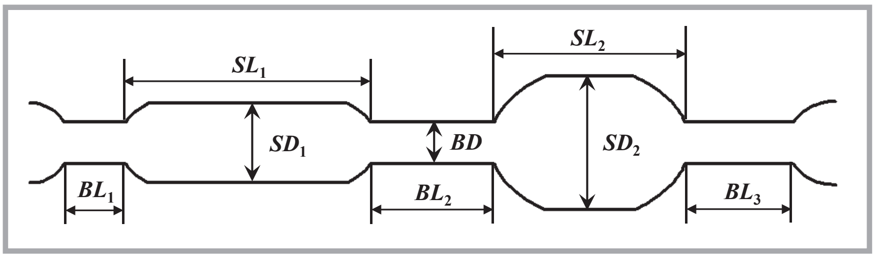

Figure 2. *Single period structure of slub-yarn.*

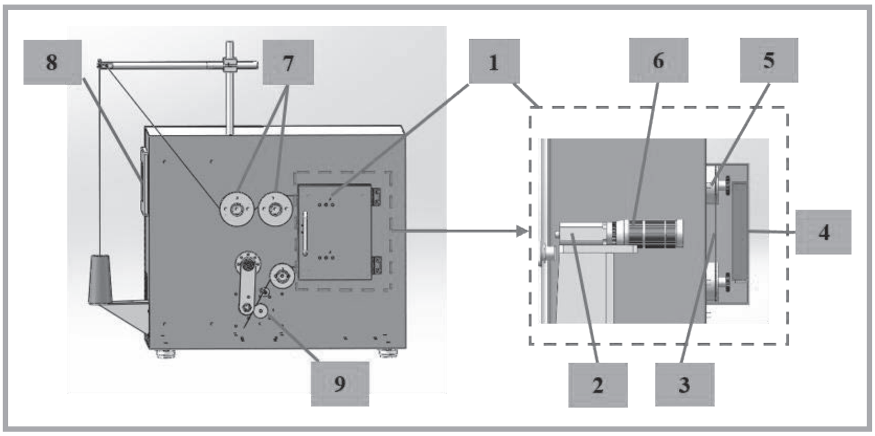

Figure 3. *Yarn image acquisition device: (1) closed imaging box, (2) area-scan CCD camera sensor, (3) yarn, (4) light source, (5) yarn guiding devices, (6) camera lens, (7) yarn tension control panel, (8) touch screen, (9) output rollers with servo motor.*

distance histogram, and Slub Length-Slub Distance distribution diagram.

For slub period measurement, spectrograms produced by the FFT method are adopted. A flowchart of the inspection process is shown in ***Figure 1***.

Experimental details

Sample preparation

In the experiment, four kinds of 100% cotton ring spun single slub yarns, as shown in ***Table 2***, were used for detecting the geometrical parameters. In the table, slub yarn sample #1, which is periodic slub yarn with a slub length and slub distance of 5cm, was specially made for this experiment. Sub yarn samples #2, #3, and #4, whose slub distance is random, were commercial slub yarn for producing fabric. For a periodic slub yarn, the geometrical parameters consist of the slub amplitude, slub length, slub distance, and slub period. A single period structure of slub-yarn is shown in ***Figure 2***. In the figure, the slub yarn is composed of two parts: the base yarn part and slub part; SL_i is the length of the slub, BL_i the length of the base yarn, and SD_i and BD are the diameter of the slub and base yarn, respectively. For a random slub yarn, BL_i is arranged randomly.

Sequence image acquisition

As reported in our earlier studies [13], sequence yarn images are taken in succession along the slub yarn by an area-scan CCD camera with a resolution of 1024 × 768 pixels. A closed imaging box is used as the image acquisition platform to shield from the disturbance of ambient light. Meanwhile a special light source is set up in the closed box. A yarn winding mechanism, servo motor, and tension controller are employed to draw the yarn, and to stabilise the yarn tension. ***Figure 3*** shows the integrated structure of this system.

For slub yarn samples #2, #3, and #4, about a 100 m length of the slub yarn is captured by the device above, respectively. For yarn sample #1, a 20 m length of slub yarn is acquired because this sample is not commercial yarn. In order to obtain accurate sequence diameter data, the neighboring slub yarn images should contain a certain level (e.g. 20-50%) of overlapping area during acquisition. In this experiment, a frame rate of 40 fps was set to capture the overlapping images. The exposure time was uniformly set as 200 μs, and the speed of the image acquisition device as 6 m/min. A background image and four kinds of slub yarn images with different yarn counts were captured by the device. These images, cropped to a suitable width to allow faster processing, are shown in ***Figure 4*** with a size of 768×600 pixels. According to the image calibration, a pixel in two directions occupies 5.21 μm in the image. The real length of yarn in this image is approximately 4 mm.

Image segmentation and stitching

In order to stitch the sequence slub yarn images, two adjacent yarn images of slub yarn #1, as shown in ***Figures 4.e1*** and ***4.e2***, are used to explain the principle of the image mosaic method. The specific steps and results of this method are as follows:

- Step 1: Remove the background information. In this part, the background image I_{bg} is subtracted from all the original images I_{og} to eliminate the impact of non-uniform brightness. The resulting images I_s after the background image ***Figure 4.e*** is subtracted from ***Figures 4.e1*** and ***4.e2*** are shown in ***Figures 5.a1*** and ***5.a2***.

- Step 2: Segment the resultant images I_s and extract yarn core images. In this part, small threshold values T_1 can be determined easily to segment image I_s to obtain a binary image I_{b1} which has clear hairiness. In order to obtain an accurate yarn core image I_{core}, the K-means clustering method is applied to determine another threshold value to segment the original image I_{og} to obtain another binary image I_{b2}. And then two judgment templates [13], which are proposed by our earlier work, are applied to process the I_{b2} images to obtain I_{core} images. By

Table 2. *Four kinds of slub yarn samples.*

Sample number	Base yarn count, tex	Parameters			
		Slub length, cm	Slub distance, cm	Slub amplitude, %	Periodicity rule
#1	27.8	5	5	200	Periodic slub
#2	27.8	4.5	13-20	150	Random slub
#3	15.6	5	35-70	140	Random slub
#4	9.7	6	15-40	150	Random slub

using all the I_{core} images, the diameter pixel values of the slub yarn can be calculated. The resultant images of I_{b1} and I_{core} are shown in ***Figures 5.a2*** and ***5.a3*** and ***5.b2-5.b3***, respectively.

- Step 3: Eliminate the yarn core image I_{core} from image I_{b1} and execute dot multiplication to obtain a test image (*TEST* image). The resultant images of subtracting image a3) from image a2) and image b3) from image b2) are shown in ***Figures 5.a4*** and ***5.b4***. ***TEST*** images of image a4, b4) dot multiplication of the original images (***Figures 4.e1*** and ***4.e2***) are shown in ***Figures 5.a5*** and ***5.b5***, respectively.
- Step 4: Image stitching. The normalised cross correlation (NCC) method [14-16] is applied to calculate the stitch position between the *TEST* 1 image and *TEST* 2 image in this paper. The NCC method is a simple template-matching method that determines the location of a desired pattern represented by a template function, t, inside a two-dimensional image function, f. A specific matrix T with a size of $H \times W$ (W = 1, 2…N) in the *TEST* 2 image is selected as the calculated template, as shown in ***Figure 6***. H and W are two adjustable parameters which represent the height and width of the template, respectively. Let $T(x, y)$ be the intensity value of T at pixel (x, y), and $f(x, y)$ be the intensity value of f at pixel (x, y). f being the movement matrix in the *TEST* 1 image, whose size is the same as T. The NCC method is evaluated at every point (u, v) for f and T, which has been shifted over the *TEST* 1 image by u-steps in the x-direction and v-steps in the y-direction. If the matrix f consists of just a part of the intensity value of the *TEST* 1 image (as shown by rectangles in ***Figure 6***, the remaining parts in matrix f are zero-filled. All the NCC coefficients are stored in a correlation matrix $\gamma(u, v)$ as defined in ***Equation (1)*** [17].

Where, $\overline{T}$ is the mean of the template and $\overline{f_{u,v}}$ that of $f(x, y)$ in the region under the template. These can be defined as:

$$\overline{T} = \frac{1}{H \times W} \sum_{x=1}^{H} \sum_{y=1}^{W} T(x, y) \qquad (2)$$

$$\overline{f_{u,v}} = \frac{1}{H \times W} \sum_{x=1}^{H} \sum_{y=1}^{W} f(u-x, v-y) \qquad (3)$$

Here, if u-x < 0 or v-y < 0 then $f(u$-x, v-$y) = 0$, and $f(0,0) = TEST(1,1)$, $f(0,1) = TEST(1, 2)$, and so on.

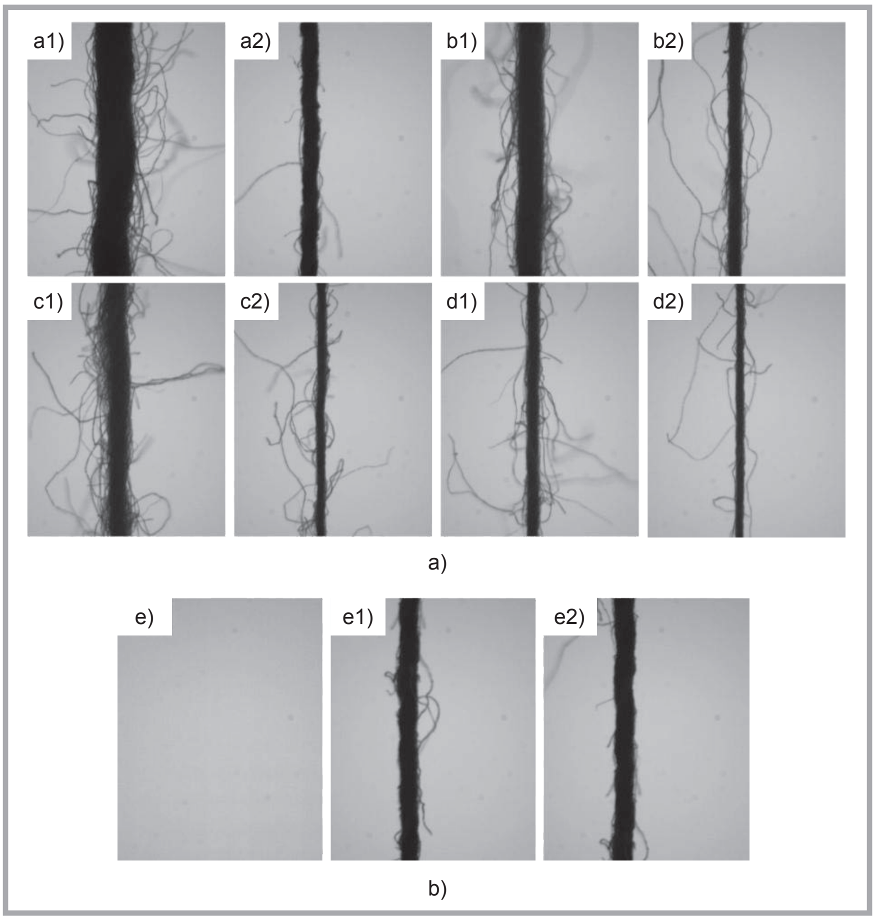

Figure 4. *Images captured: (a) Four kinds of slub yarn images: a1) sample #1 – part image of base yarn, a2) sample #1 – part image of slub, b1) sample #2 – part image of base yarn, b2) sample #2 – part image of slub, c1) sample #3 – part image of base yarn, c2) sample #3 – part image of slub, d1) sample #4 – part image of base yarn, d2) sample #4 – part image of slub; (b) Sequence images of slub yarn sample #1, e) background image, e1) second image, e2) first image.*

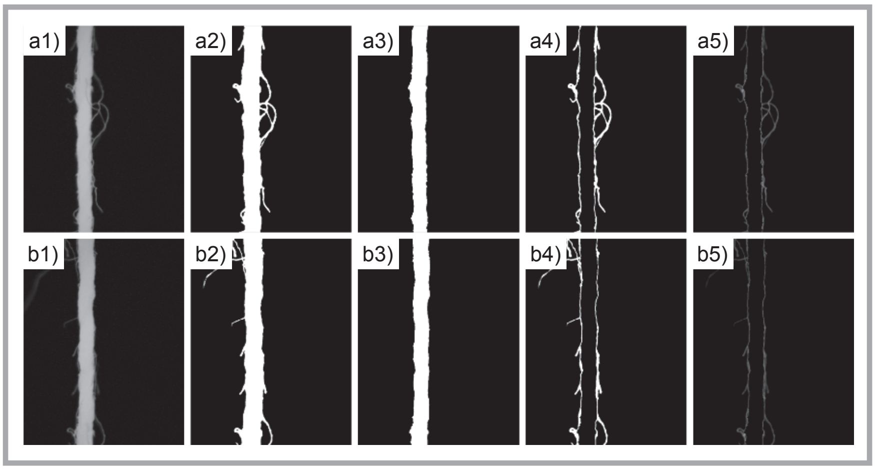

Figure 5. *Image processing results of two example images: a1)-b1) images after background removal, a2)-b2) binary images with clear hairiness, a3)-b3) yarn core images, a4)-b4) binary-hairiness images, a5)-b5) gray-hairiness images (TEST 1 and TEST 2 image).*

$$\gamma(u,v) = \frac{\sum_{x=1}^{M} \sum_{y=1}^{N} \left[T(x,y) - \overline{T}\right]\left[\overline{f_{u,v}} - f(u-x, v-y)\right]}{\left\{\sum_{x=1}^{M} \sum_{y=1}^{N} \left[T(x,y) - \overline{T}\right]^2 \times \sum_{x=1}^{M} \sum_{y=1}^{N} \left[f(u-x, v-y) - \overline{f_{u,v}}\right]^2\right\}^{0.5}} \quad \begin{matrix} u \in (1,2,,,M+H-1) \\ v \in (1,2,,,N+N-1) \end{matrix} \qquad (1)$$

Equation (1).

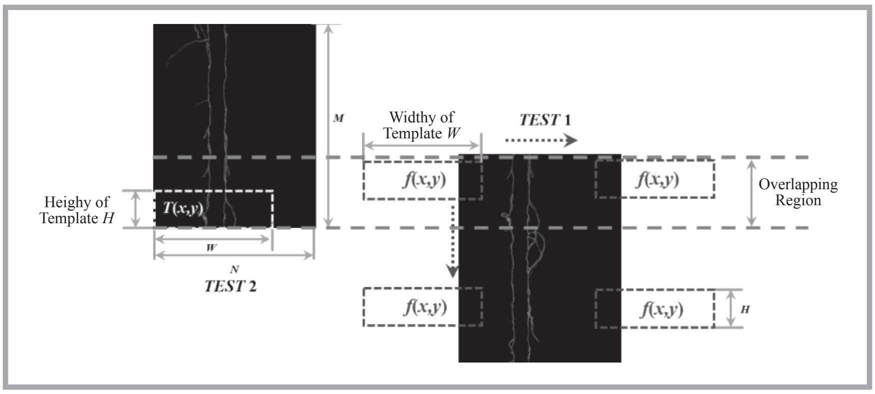

Figure 6. *Computation principle of NCC method for slub yarn sequence image.*

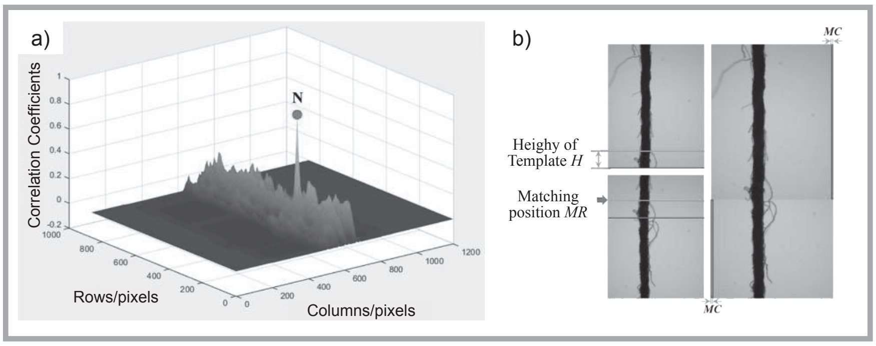

Figure 7. *Stitch position information and mosaic result of two* TEST *images.*

In this paper, we set $H = 100$ pixels and $W = N$. After the calculation, the correlation matrix $\gamma(u, v)$ is obtained as shown in ***Figure 7.a***. In the figure, there is a quite distinct peak at point N, which denotes that the position of point N is the optimum matching position of the two adjacent slub yarn images. Suppose the position of point N is (u_p, v_p), then the matching position in the *TEST* 1 image, that is, the matching row *MR* and matching column *MC*, can be calculated as:

$$MR = u_p - H \tag{4}$$

$$MC = v_p - W \tag{5}$$

The values of *MR* and *MC* are adopted to find the overlapping line between two adjacent yarn images in order to stitch the yarn images. Finally the original image of *TEST* 1 is separated based on *MR* and *MC*, and a panoramic image is obtained, as shown in ***Figure 7.b***. In the figure the regions represent the width of *MC*.

When the *MR* values of all the sequence images are obtained, the overlapping regions are removed and sequence diameter data of the slub yarn can be reordered. Then these reordered data are adopted to detect the geometrical parameters of the slub yarn.

Geometrical parameter analysis and discussion

Explanation of terms

Reference level

The reference level is a line which is on the level of the base yarn [18]. All slub yarn calculations are based on this reference level. Using this line, the slub part can be separated from the slub yarn. Thus determination of the reference level is very important for the inspection of the geometrical parameters of slub yarn. In this paper, we use the Gaussian distribution function of the slub yarn diameter data to confirm the reference level value automatically. As we know, there are more than two wave crests in the frequency histogram of slub yarn diameter data [6, 10]. Take ***Figure 8*** as an example, there are just two wave crests in the frequency histogram, which means this slub yarn has just one type of slub. In this frequency histogram, P_1 and P_2 are the frequency values of the first and second wave crest, respectively, and D_1 and D_2 are the diameter values of the first and second wave crest, respectively. Thus we can use D_1 to represent the diameter of the base yarn part, and D_2 to represent the diameter of the slub part. From the frequency histogram, we can also find a valley between the first wave crest and second wave crest, which can be determined by fitting the histogram values. In order to determine the reference level value, the Gaussian distribution functions (F1 and F2) of all the wave crests are fitted. Then a crossing point D_3 (as shown in ***Figure 8*** between D_1 and D_2 can be calculated. Finally the reference level value is obtained by ***Equation (6)***:

$$D = \frac{D_2 + D_3}{2} \tag{6}$$

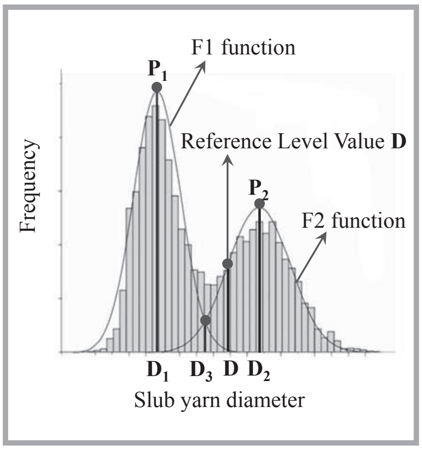

Figure 8. *Frequency histogram of slub yarn diameter data.*

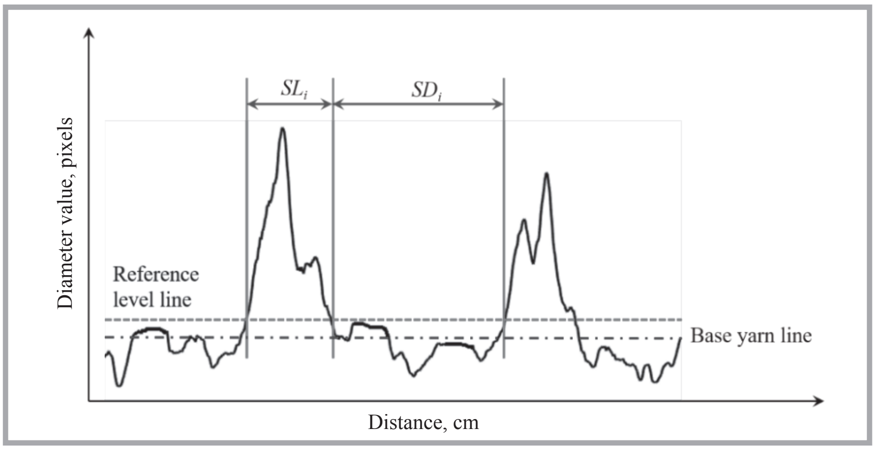

Figure 9. *Smoothed diameter data signal.*

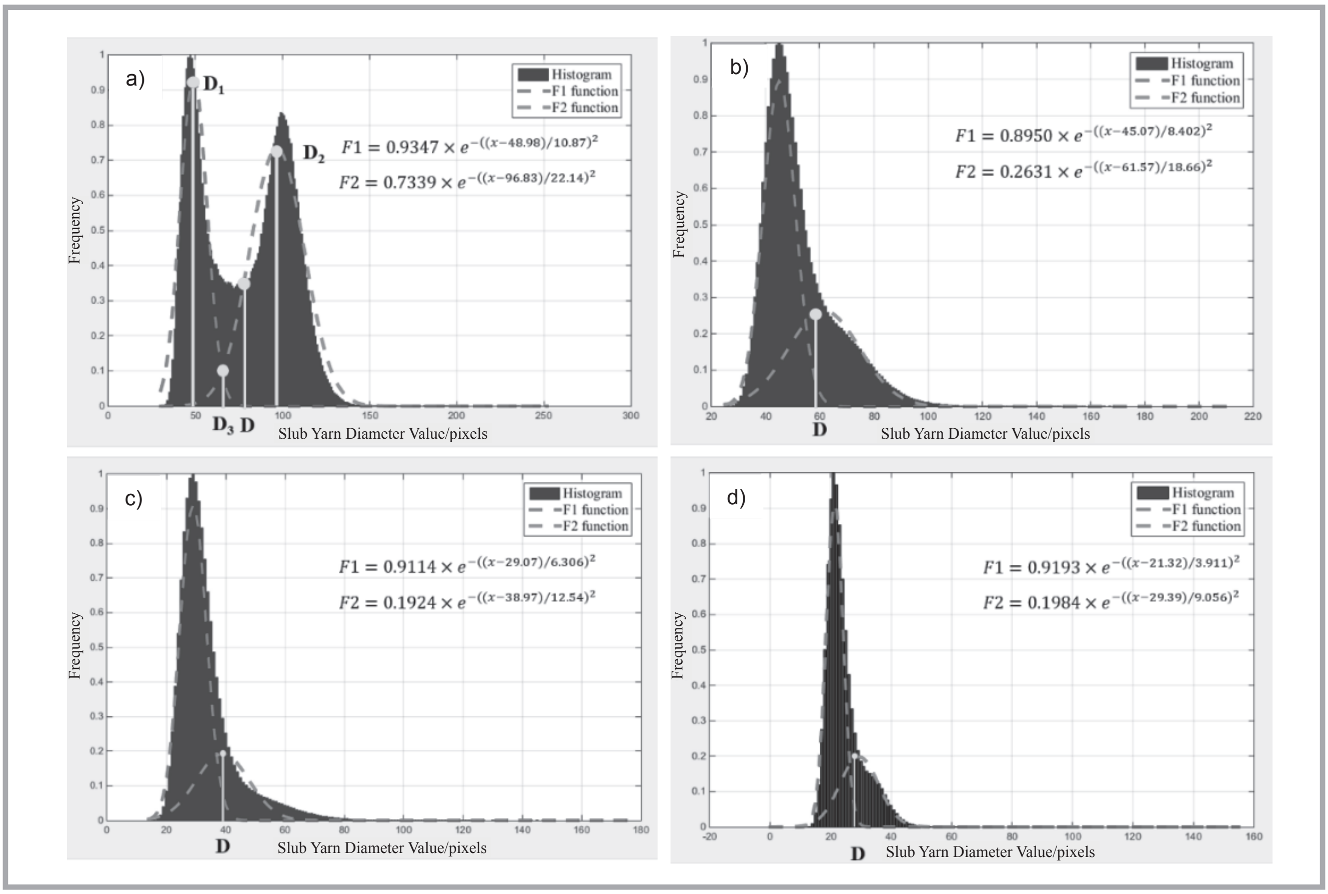

Figure 10. *Frequency histograms and Gaussian distribution functions of four kinds of slub yarn.*

Slub amplitude

In this paper, the slub amplitude (SA) is defined as:

$$SA_i = \frac{D_{i+1}}{D_1} \times 100\% \quad i = 1, 2, ..., N \qquad (7)$$

Where, SA_i represents the ith slub amplitude, and D_{i+1} the diameter value of the i+1 th wave crest in the frequency histogram. D_1 is the diameter value of the first wave crest in the frequency histogram. If there are just two wave crests in the frequency histogram, there is only one type of slub amplitude.

Slub length (SL) and slub distance (SD)

When the reference level is determined, the slub part can be separated from the yarn. As shown in ***Figure 9***, the ith slub length (SL_i) and ith slub distance (SD_i) can be calculated based on the reference level from a smoothed diameter data signal.

Slub period

The spectrogram is an ideal tool to check the repeat pattern of slubs. In order to obtain the slub period, the Fast Fourier Transform (FFT) is used to analyse the spectrogram base for 1D continuous slub yarn diameter data in this paper. Wavelengths (W_l) are calculated based on the resolution of the slub yarn image, as in ***Equation (8)***.

$$W_l = \frac{N_i}{N_t \times \Delta t} \quad N_i \in [0, 1, ..., N_t] \qquad (8)$$

Where, N_t is the total length of the 1D continuous slub yarn diameter data, Δt the resolution of the slub yarn image, and Δt = 5.21 μm in this paper.

Experimental results and discussion

Frequency histogram

In order to determine the reference level value D and slub amplitude SA, the frequency histograms of four kinds of slub yarn are shown in ***Figure 10***. In these figures, the Gaussian distribution functions F1 and F2 of each slub yarn are fitted based on the histograms. D_1 and D_2 represent the diameter values of the first and second wave crest, respectively. D_3 represents the diameter value of the crossing point of functions F1 and F2. After the function approximation and cross point calculation, the D_1, D_2, D_3, D, and SA values of the four kinds of slub yarn are listed, shown in ***Table 3***.

It can be seen from ***Table 3*** that the D_1 values of the four samples are #4<#3<#2 & #1. Those of #1 and #2 are similar, which is consistent with the actual base yarn count of the four samples: #4<#3<#2=#1. In the Table, the reference line values D of the four samples determined are 81, 59, 38, and 29 pixels. It can also be found that the SA values of the four samples (198%, 138%, 134%, 138%) are close to the set values (200%, 150%, 140%, 150%). Thus the method proposed can be applied to inspect the slub amplitude.

Table 3. *Five numerical results of four kinds of slub yarn.*

Slub yarn sample	D_1/pixels	D_2/pixels	D_3/pixels	D/pixels	SA, %
#1	49	97	65	81	198
#2	45	62	55	59	138
#3	29	39	37	38	134
#4	21	29	26	28	138

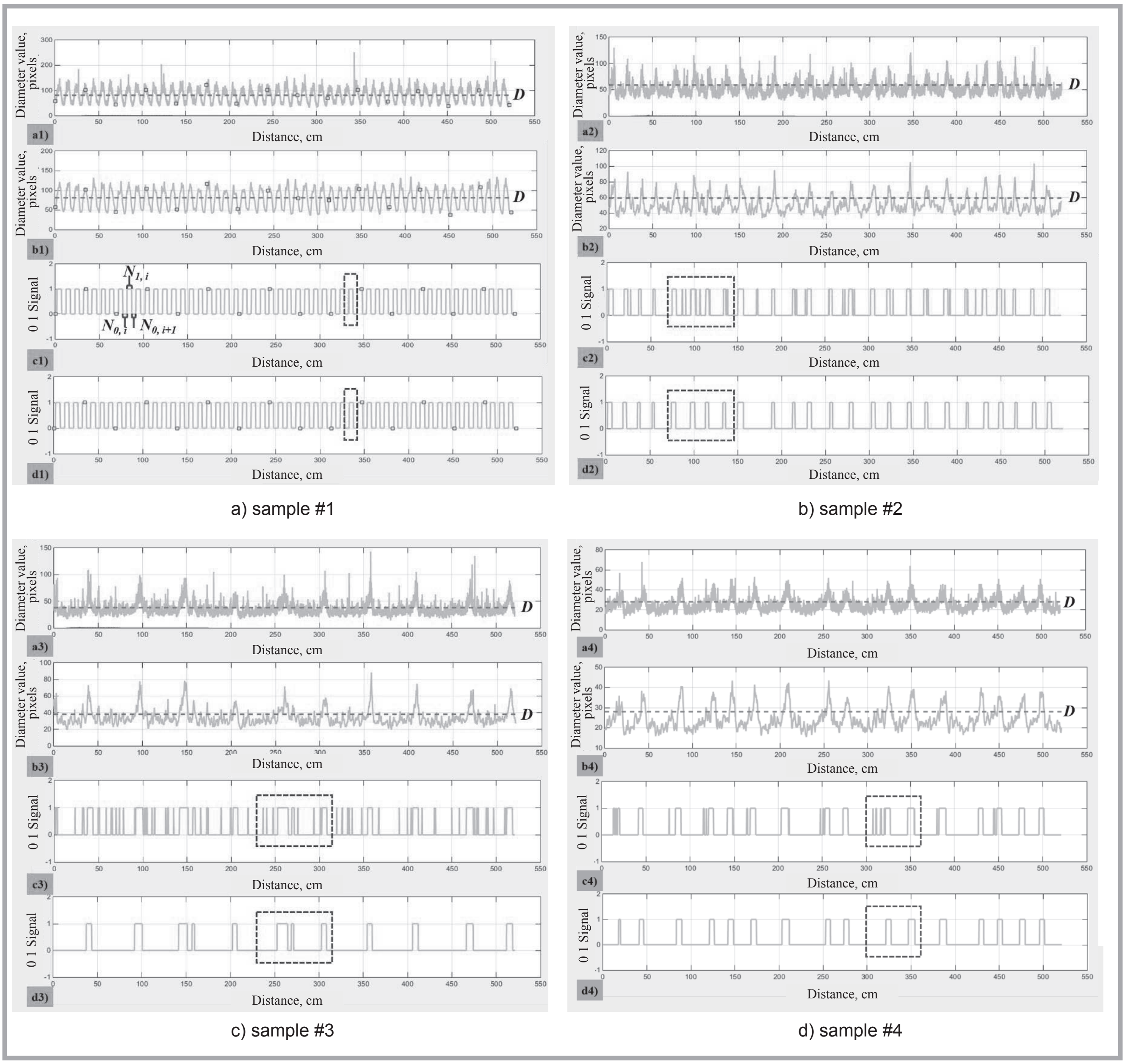

***Figure 11**. Part diameter data of four samples: a1)-a4) Original sequence diameter data, b1)-b4) Smoothed diameter data, c1)-c4) Original "0 and 1" data signals, d1)-d4) The processed "0 and 1" data signals.*

Slub length and slub distance analysis

Since irregular variation of slub yarn diameter data exists, there are some burrs and noises in the original sequence diameter data. These may cause some errors when calculating the slub length and slub distance using the reference level value D. Therefore the diameter data need to be smoothed first. A part of the original diameter data and the smoothed data of the four yarn samples are shown in ***Figures 11.a1-11.a4*** and ***11.b1-11.b4***. After the diameter data is smoothed, the smoothed data which is greater than the reference level value D is set 1 and the other – set 0. The "0 and 1" data signals are shown in ***Figures 11.c1-11.c4***. From ***Figures 11.c1-11.c4***, we can see that although the original data have been smoothed first, there are also some outliers, as shown in the dot blue rectangle. In order to obtain accurate results, the following steps are applied to process the "0 and 1" data signals in ***Figures 11.c1-11.c4***:

- Step 1: Count the number of consecutive 1 and 0 data from the "0 and 1" data signal, and denote them as $N_{1,\ i}$ (representing the slub length sequence, $i = 1,\ldots, n$) and $N_{0,\ i}$ (representing the slub distance sequence, $i = 1,\ldots, n$), as shown in ***Figure 11.c***.
- Step 2: The slub length and slub distance will be not be shorter than 20 millimeters during the yarn production [6]. Therefore if $N_{1,\ i} < 2$ cm, $N_{0,\ i} < 2$ cm, and $N_{0,\ i+1} < 2$ cm, the data in $N_{1,\ i}$ will be considered as the base yarn part and set as 0.
- Step 3: If $N_{1,\ i} > 2$ cm, $N_{0,\ i} < 2$ cm, and $N_{0,\ i+1} < 2$ cm, the data in $N_{1,\ i}$ and $N_{1,\ i+1}$ will be combined together and set as 1.

Through the three steps above, the resultant data of the four samples are shown in ***Figures 11.d1-11.d4***. From these Figures, we can see that the outliers in the dotted rectangles are almost removed or combined.

When the processed "0 and 1" data signals are obtained, the slub length and

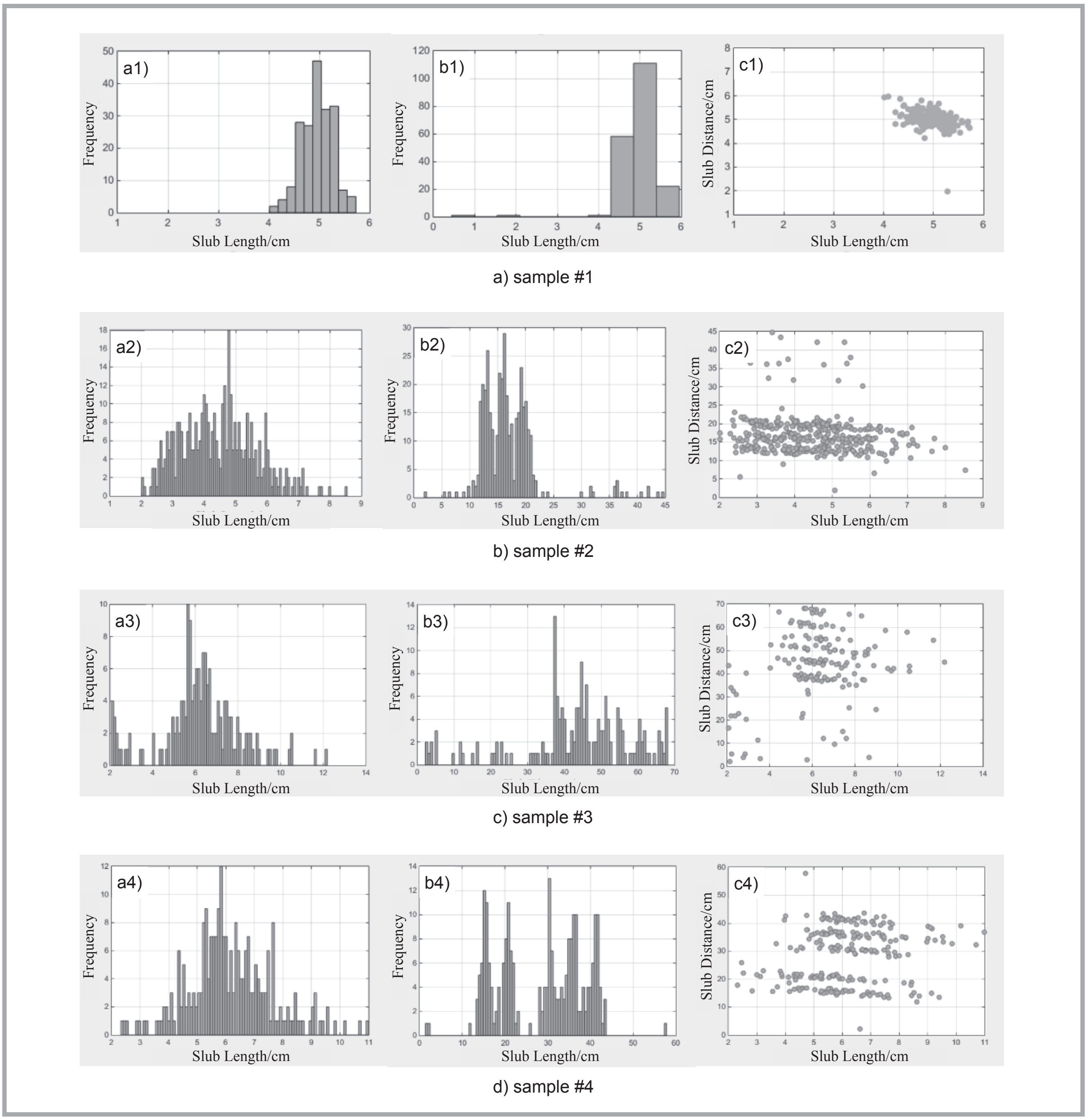

***Figure 12**. Detection results of four slub yarn samples: a1)-a4) frequency histogram of slub length, b1)-b4) frequency histogram of slub distance, c1)-c4) distribution diagram of slub length-slub distance.*

slub distance can be counted. Then a slub length histogram, slub distance histogram and Slub Length-Slub Distance distribution diagram of the four samples are constructed, shown in ***Figure 12***.

From ***Figures 12.a1-12.a4***, we can find that although the slub length is dispersed in different intervals, there is no obvious multimodal on these histograms. Furthermore the four samples all have two wave crests in the frequency histogram of the sequence diameter data (as shown in ***Figure 10***). Thus we can determine that the four samples have just one type of slub length. The abscissa value of each crest wave in ***Figures 12.a1-12.a4*** is measured as the slub length of each sample, as shown in ***Table 3***.

It can be seen from ***Figures 12.b1-12.b4*** and ***Figures 12.c1-12.c4*** that there are one, three, six, and five dominant peaks. Thus the slub distance can be measured using these peaks. The results measured are also listed in ***Table 4***.

It can be seen from the table above that the slub length and slub distance measured are very close to the set values. This can prove that the reference level value we selected from the histogram is correct. From the Table, we can also find that sample #1, which has one type of slub length and slub distance, is periodic slub yarn. The slub period of sample #1 is about 10 cm. For samples #2, #3, and #4, they all have just one type of slub length and different types of slub distance. Thus the three samples are all random slub yarn.

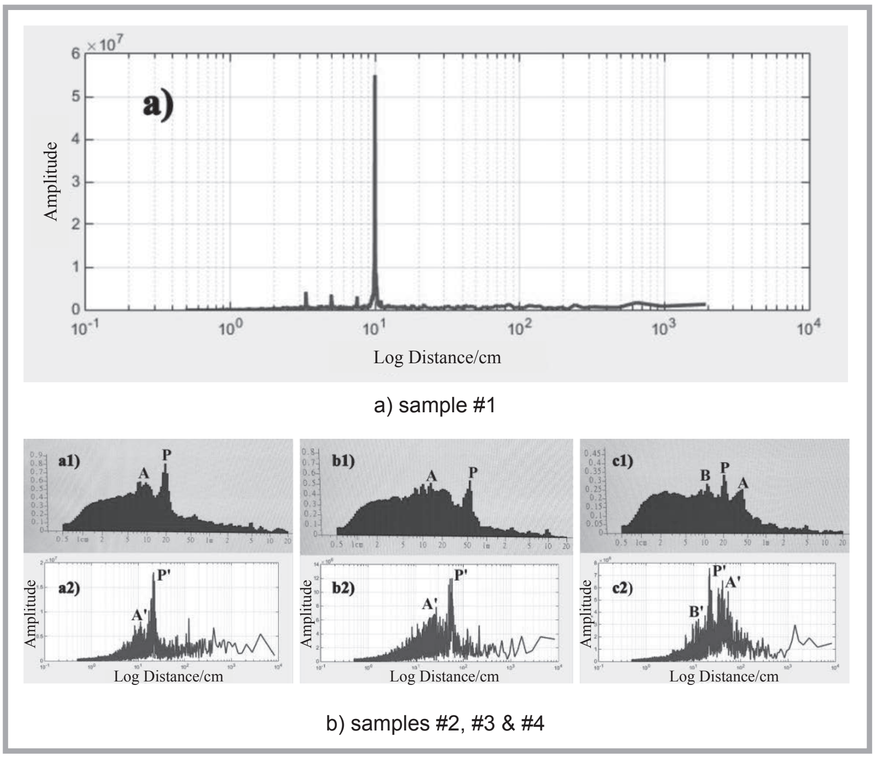

Figure 13. *Spectrograms for four yarn samples: (a) FFT, #1; a1) Uster, #2; b1) Uster, #3; c1) Uster, #4; a2) FFT, #2; b2) FFT, #3; c2) FFT, #4.*

Spectrogram

The spectrogram is utilised to detect the periodic variations of slub yarn. Due to sample #1 being produced specifically in a shorter length, the Uster Tester was not used to detect its spectrogram. The spectrogram of sample #1 generated by the FFT method is shown in ***Figure 13.a***. The spectrograms of samples #2, #3 and #4 obtained from the Uster Tester are shown in ***Figures 13.a1-13.c1***, respectively. The FFT spectrograms of samples #2, #3 and #4 produced from the slub yarn sequence images are also illustrated in ***Figures 13.a2-13.c2***.

From ***Figure 13.a***, we can see that there are four peaks on the spectrogram produced by the FFT method for slub yarn sample #1, which are located at about 3.32, 4.98, 8.18 and 9.97 cm. The peak at the wavelength around 3.32 cm can be attributed to mechanical faults and drafting waves, and that located around 4.98 cm can be attributed to the inter-slub distance. The peak around 8.18 cm can be attributed to mechanical faults (about 3.32 cm) plus the inter-slub distance (4.98 cm). The dominant peak at 9.97 cm can be attributed to the pattern of the long slub (4.95 cm) plus its inter-slub distance (4.98 cm). Thus we can conclude that the slub period of sample #1 is 9.97 cm, which is very close to the set value of 10 cm.

From ***Figures 13.b***, we can find that the dominant peaks on spectrograms obtained from FFT are very consistent with the Uster spectrograms. The position of dominant peaks in the Uster (located at point ‘P’, ‘A’ or ‘B’) and FFT spectrograms (located at point ‘P’’, ‘A’’ or ‘B’’) are all similar for samples #2, #3 and #4. The corresponding wavelengths range of point ‘P’, ‘A’ and ‘B’ in the Uster spectrograms and the corresponding wavelengths of point ‘P’’, ‘A’’ and ‘B’’ in the FFT spectrograms for samples #2, #3, and #4 are listed in ***Table 5***.

From ***Table 5***, we can conclude that the method proposed for measuring the periodicity of slub yarn is quite consistent with the Uster method. Especially for the ‘P’ and ‘P’’ points, the two kinds of spectrograms have almost the same values. However, there are also some inconsistencies between the two spectrograms with respect to the three samples because of the principle of the Uster spectrogram and FFT spectrogram. The Uster spectrogram divides the interval of the channel and calculates the integral of the channel, whereas the FFT spectrogram dies not.

Due to samples #2 #3, and #4 being random slub yarn and that irregular variation exists, it is hard to obtain the arrangement of different slub distances from the spectrograms above. However, for sample #1 the arrangement of different slub distances can be obtained from the spectrogram because sample #1 is not random slub yarn. Finally the geometrical parameters, consisting of the slub amplitude, slub length, slub distance, and the slub period, of the four samples all are detected. And the results analysed are in high accordance with the set values and Uster Tester results.

Table 4. *Detection results of slub length and slub distance.*

Yarn sample	Slub length measured, cm	Slub length set, cm	Slub distance measured, cm	Slub distance set, cm
#1	4.95	5	5.1	5
#2	4.78	4.5	13.2, 16.2, 19.2	13-20
#3	5.66	5	37.5, 44.7, 51.3 54.6, 60.6, 67.8	35-70
#4	5.84	6	15.2, 20.8, 30.4, 36.7, 41.2	15-40

Table 5. *Corresponding wavelengths of the dominant peaks on two kinds of spectrograms.*

Dominant peak points	#2	#3	#4
P	[19 cm, 21 cm]	[50 cm, 60 cm]	[20 cm, 21 cm]
P'	21.3 cm	57.7 cm	21.9 cm
A	[7.5 cm , 11 cm]	[14 cm, 15 cm]	[41 cm, 43 cm]
A'	11.2 cm	19.3 cm	41.5 cm
B	–	–	[11 cm, 13 cm]
B'	–	–	12.9 cm

Conclusions

In this paper, the geometrical parameters of slub yarn are measured from slub yarn sequence images using image processing technology. The image segmentation method proposed in our earlier work is applied to obtain the overlapping diameter data of slub yarn. Then an image stitching method is utilised to remove the overlapping part based on the NCC method to gain the sequence diameter data of the slub yarn. Finally the sequence diameter data are used to detect the geometrical parameters of the slub yarn.

In the experiment, the reference level value and slub amplitude of each sample were determined first from the frequency histogram of the sequence diameter data. Then the slub length and slub distance were measured by the slub length histogram, slub distance histogram, and Slub Length-Slub Distance distribution diagram. Finally the slub period was analysed by means of the spectrogram.

From the measurement of the slub amplitude, the detection results of four samples are as follows: 198%, 138%, 134%, and 138%. They are close to the set values of 200%, 150%, 140%, and 150%.

For the measurement of slub length, the detection results of four samples are: 4.95, 4.78, 5.66, and 5.84 cm. They are also very close to the set values as 5, 4.5, 5, and 6 cm.

From the measurement of the slub distance, we detect that sample #1 has just one type of slub distance, with a value of 5.1 cm, which is close to the set value of 5 cm. For samples #2, #3 and #4, there are three, six, and five types of slub distance, respectively, whose values are (13.2 cm, 16.2 cm, 19.2 cm), (37.5 cm, 44.7 cm, 51.3 cm, 54.6 cm, 60.6 cm, 67.8 cm), and (15.2 cm, 20.8 cm, 30.4 cm, 36.7 cm, 41.2 cm). They are all similar to the setting interval, namely [13 cm, 20 cm], [35 cm, 70 cm], and [15 cm, 40 cm].

From the spectrograms of the four samples, we can conclude that sample #1 is periodic slub yarn, with a slub period 9.97 cm, which is constant with the set value of 10 cm. For samples #2, #3 and #4, spectrograms detected all conform to the Uster spectrograms. Finally, combining the measurement results of slub length and slub distance with the spectrograms of the three samples, we can conclude that samples #2, #3, and #4 are all random slub yarns. Therefore the method proposed can be used to measure the geometrical parameters of slub yarn, and it can obtain accurate results.

Acknowledgements

The authors would like to acknowledge the Research Innovation Program for College Graduates of Jiangsu Province (Grant No. KYLX_1132); the National Natural Science Foundation of China (grant number 61802152), the Natural Science Foundation of Jiangsu Province (grant number BK20180602), the China Postdoctoral Science Foundation Funded Project (grant number 2018M640453), the Jiangsu Province Postdoctoral Science Foundation (grant number 2018K037B), and the Fundamental Research Funds for the Central Universities (grant number JUSRP51907A).

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Received 24.01.2018 Reviewed 28.11.2018