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System Design for Evenness Measurement of Raw Silk

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Abstract
The evenness of raw silk is one of its most valuable qualities. Seriplane inspection is a common test for raw silk evenness but is prone to human error and lacks accurate repeatability; the Uster evenness tester is another common approach but is costly and vulnerable to environmental factors. An image-based raw silk evenness detection system is proposed in this paper. The system is comprised of an image acquisition segment with a CCD image sensor, telecentric lens, light source, over feeding device, and raw silk winding device, plus an image processing segment tasked with threshold segmentation and morphology operations. Images of the raw silk are first captured with the image acquisition segment, then the images are processed by threshold segmentation and morphology processing; the diameters obtained in this segment are then used to calculate the variation coefficient (CV), which characterises the evenness of the raw silk. We conducted three experiments to test the stability, repeatability, and accuracy of the system. The results showed that the system proposed is stable, repeatable, and accurate.

Key words: *image vision, raw silk evenness, diameter extraction, variation coefficient (CV), system verification.*

Introduction

Raw silk is a widely popular natural protein fibre that has a pleasant texture and aesthetic appeal. There is a natural unevenness on the surface of raw silk because it is naturally formed by silkworms; such unevenness impacts the quality of the silk and the appearance of raw silk fabrics. Effectively and efficiently inspecting raw silk for its evenness is crucial to ensure high-quality, valuable fabrics[1]. Seriplane inspection is the most common traditional method of raw silk inspection. It is easily operated and intuitive, but as it depends on a human inspector, it readily falls subject to operator error [2].

The Uster evenness tester first grew popular for testing the quality of yarn raw silk in the 1990s and is still in use today [3]. It uses the principle of capacitance conversion and has better objectivity and repeatability than seriplane inspection. However, the system is easily influenced by external factors and has relatively poor recognition accuracy (the minimum recognition length is 8 mm), hence it is difficult to apply to raw silks with high moisture regain and small volume. Besides there are many other electronic detection methods used in the inspection of yarn or raw silk evenness. Carvalho, Chen Ling, Qin Weiguang, Ji Jianzheng, Wanchun Fei etc. introduced inspection methods for yarn or raw silk evenness based on the technology of photoelectric detection [4-8]. But both photoelectric detection and capacitance are indirect ways of detection [3].

The auto-inspection of raw silk based on image vision and image processing techniques represents the newest trend in raw silk inspection technology. The small diameter of raw silk is challenging in terms of image acquisition and image processing, however. This paper proposes a novel image-based raw silk evenness detection system. And experiments prove that the system has excellent stability, repeatability,and accuracy, which will meet the future inspection requirements of raw silk.

Configuration of the evenness measurement system

The framework of the raw silk evenness measurement system is shown in ***Figure 1***.

The method is comprised of an image acquisition system and image processing system. The image acquisition system includes 1) raw silk, 2) an over feeding device (BTSR,SM-DIN/RW, Italy), which keeps the raw silk moving

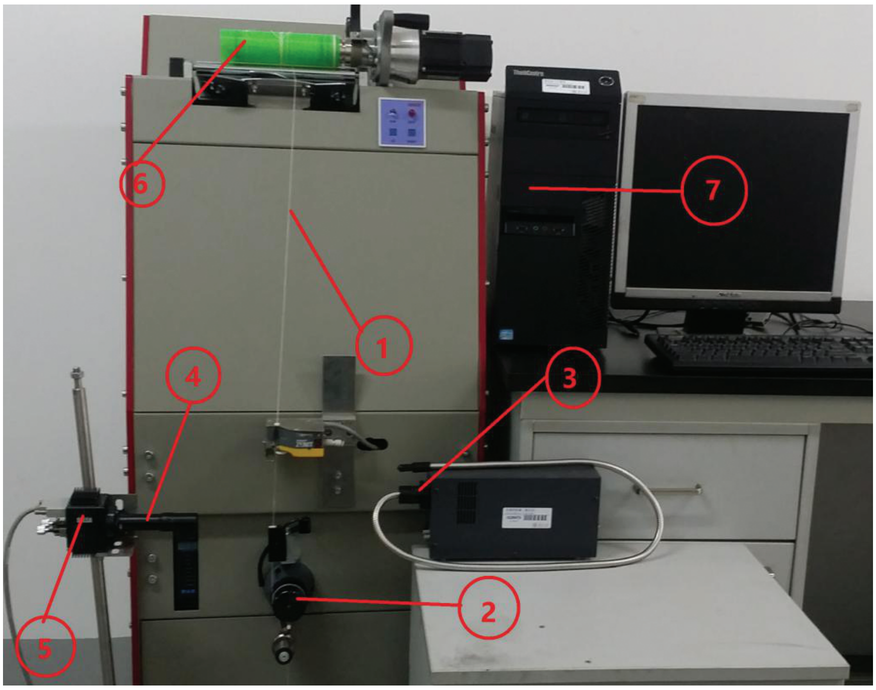

Figure 1. *Raw silk evenness detection system: 1) raw silk, 2) over feeding device, 3) light source, 4) telecentric lens, 5) CCD line scan camera, 6) variable-speed raw silk winding device, 7) image processing computer.*

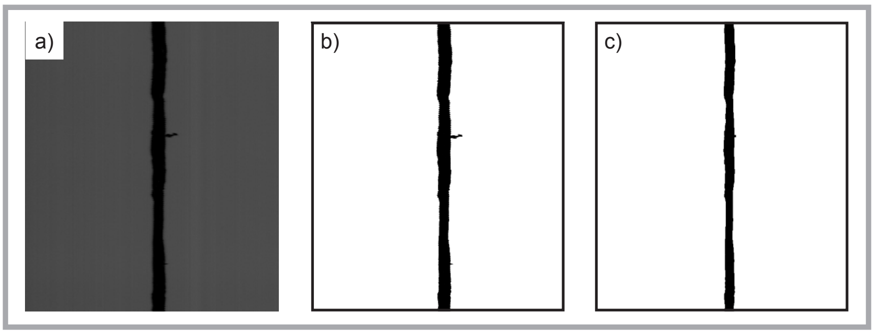

Figure 2. Raw silk image processing: a) original image, b) image after threshold segmentation, c) image after threshold segmentation and mor-phology processing.

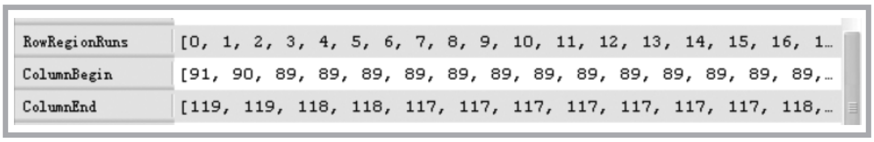

Figure 3. *Halcon variable display.*

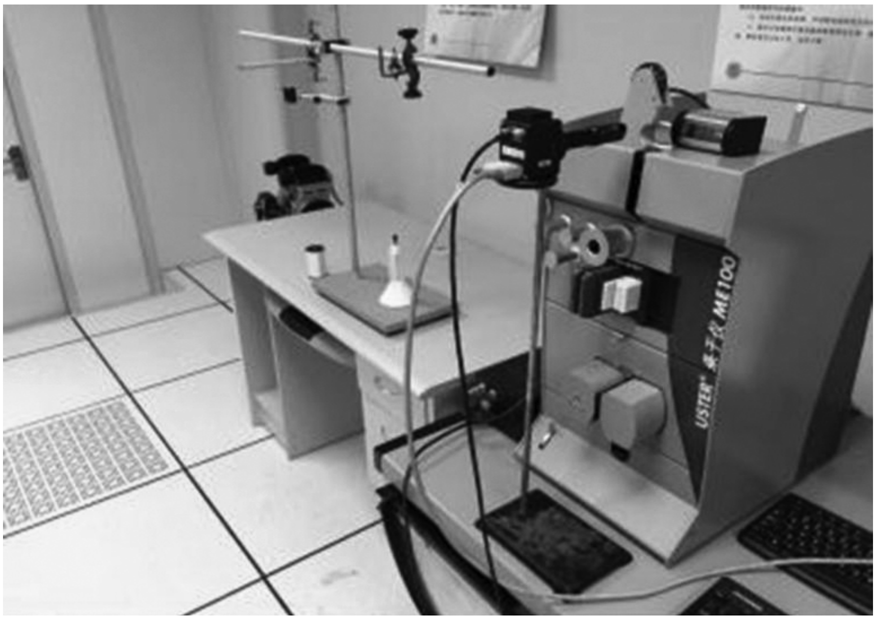

Figure 4. *Synchronous detection.*

stabily; and 3) a light source (U-TECHNOLOGY-UFLS). A back light is selected, which is placed on one side and a camera on the other side of the raw silk sample. The system also contains 4) a telecentric lens, with 6X magnification (MGTL60C), 5) a CCD line scan camera (Dalsa S2-1y-05H40, Canada) with 512 resolution, 14 μm×14 μm pixel size, 65 kHz maximum line frequency, which meets the accuracy requirements, and 6) a variable-speed raw silk winding device, which drives the raw silk from the bottom up at a certain speed.

First images of the moving raw silk were captured using the image acquisition system and stored on an image processing computer 7) via an image capture card (Dalsa Xcelera-c1 LX1, Canada) and Halcon software. Next the images were processed by the image-processing system, and the thresholding segmentation and morphology operation were selected. Finally, the diameters were extracted from the treated images and used to calculate the variation coefficient (CV) of each sample.

System operation

Raw silk image acquisition

Halcon software, which is a professional software in the field of image vision, was used for capturing and processing the raw silk image in this system [9]. Halcon software integrates a set of perfect machine vision algorithms that are quick and cost-effective. Raw silk images were continuously acquired in Halcon as follows:

1) The "open_framegrabber" function parameter was set to "SperaLT" to open the image acquisition card and import the selected ccf camera configuration file.
2) A loop was created and the"grab_image_async" function was selected to acquire the image in the loop, then the "write_image" function was used to save the image.
3) The image acquisition card was closed and the acquisition loop ended with the "close_framegrabber" function.

Raw silk image processing

Image processing was selected to reduce background interference and minimise defects prior to diameter extraction. In the system proposed, the background and raw silk image are separated by threshold segmentation, and morphology processing resolves small defects. Both operations are executed in Halcon [3]. The original image, that after threshold segmentation, and the image after threshold segmentation and morphology processing are shown in ***Figures 2.a-c*** (magnification 6x), respectively.

Diameter extraction and CV values

The raw silk region was extracted from the image after threshold segmentation and morphology processing, and then we tested its evenness by calculating its diameter and CV. There is a positive correlation between changes in evenness and diameter [10-12], thus acquiring the silk's diameter is the precondition for determining its evenness. The diameter was then used to calculate the CV value, which can be considered to effectively characterise the evenness of the sample.

Diameter extraction

The size of the processed region, shown in ***Figure 2.c***, was 512 * 2400. The linear array camera scanned the image line-by-line, thus every image was scanned for 2400 lines and 2400 diameters. The stepwise diameter extraction procedure was as follows:

1) Preprocessed images were scanned from top to bottom and from left to right;
2) The initial pixel coordinate M1 and ending pixel coordinate M2 of every line of the trunk were recorded;

3) The diameter (M) value was calculated as follows:

$$M = M2 - M1 + 1 \quad (1)$$

4) Steps 2-3 were repeated until all diameters were obtained.

The "get_region_runs" function of Halcon software was used for diameter extraction [8]. Row Region Runs which represented row coordinates, and Column Begin (M1) and Column End (M2) representing column coordinates were the three output parameters of the function. ***Figure 3*** shows the results as displayed by Halcon. The array (including every line's diameter) was obtained via ***Equation (1)***.

Calculating CV

CV can well reflect variations in raw silk evenness over both long and short fragments obtained via electronic detection. CV can be calculated as follows:

$$\mathrm{CV} = \frac{1}{\overline{x}}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2} \times 100 \quad (2)$$

Where, $\overline{x}$ is the average diameter, n the total number of diameters, and x_i the i-th diameter value.

CV is a relative value and has no unit, hence we used the number of occupied pixels (which was directly obtainable in Halcon) rather than the real diameters to calculate the CVs.

Experiment and discussion

We tested the stability, repeatability, and accuracy of the system proposed in three separate experiments.

System stability tests

We first tested the stability of the system over an increasing test time. Polyester filament (20D linear density) was used for this purpose as it does not contain any variations in evenness. Three groups of samples were tested over 5 h at a speed of 2 m/min. ***Table 1*** shows the results (the testing index is CV).

Table 1. Stability test results.

Group's Test time	1 h	2 h	3 h	4 h	5 h
1	0.48	0.50	0.49	0.49	0.49
2	0.48	0.51	0.49	0.44	0.49
3	0.50	0.51	0.50	0.50	0.48

These results were then inputted to SPSS software for analysis of variance (ANOVA), the results of which are shown in ***Table 2***.

Table 2. ANOVA results.

	Sum of squares	df (Degree of freedom)	Mean square	F	Significance
Between groups	0.001	4	0.000	1.447	0.289
Within groups	0.003	10	0.000		
Total	0.004	14			

As shown in ***Table 2***, the significance of the time factor on polyester filament evenness was 0.289 > 0.1, suggesting that time did not exert any significant impact on evenness (at the 0.1 level). In other words, the system proposed has excellent stability.

System repeatability tests

Due to the poor repeatability of seriplane inspection, we placed extra emphasis on testing the repeatability of the system proposed. We again used polyester filament 1000 m in length and with 20D linear density and ran tests at 2 m/min speed. We tested three groups of requested samples and each group was repeated twice. The results are shown in ***Table 3***.

Table 3. Repeatability test results.

Groups repetitions	First time, CV%	Second time, CV%
1	1.91	1.88
2	1.97	1.96
3	1.96	1.98

The correlation coefficient r of the two measured values of the same object can be used to measure repeatability:

$$r = \frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sqrt{\sum(x_i-\overline{x})^2}\sqrt{\sum(y_i-\overline{y})^2}} \quad (3)$$

We again used SPSS software to analyse the data; the results are shown in ***Table 4***.

Table 4. Correlation analysis results.

Analysis indexes repetitions		First time	Second time
First time	Pearson correlation	1	0.941
	N	3	3
Second time	Pearson correlation	0.941	1
	N	3	3

The correlation coefficient of the two tests reached 0.941, indicating that the system has favorable repeatability.

System accuracy tests

The Uster evenness tester is the universally acknowledged testing device for yarn and raw silk evenness. We compared the accuracy of our system against that of the Uster (ME100) for the sake of comparison, as shown in ***Figure 4***. The experimental parameters are shown in ***Table 5***.

Table 5. Experimental parameters.

Test material	20/22D raw silk
Test speed	50 m/min
Test length of each experiment	200 m
Experimental groups	6
Experimental environment	Standard atmospheric conditions
Testing index	CV (%)

Test results and data analysis

The accuracy test results are shown in ***Table 6***. ***Figure 5*** provides a line chart of these results that indicates the trend of the two sets of data.

The difference between our system and the Uster evenness tester was substantial. Our system yielded higher result than the Uster for a couple of likely reasons. 1) The Uster system tests for the CV of mass, while ours tests for the CV of the diameter. 2) The detection accuracy of our system was 2.33 μm (telecentric lens magnification was 6X and camera pixel

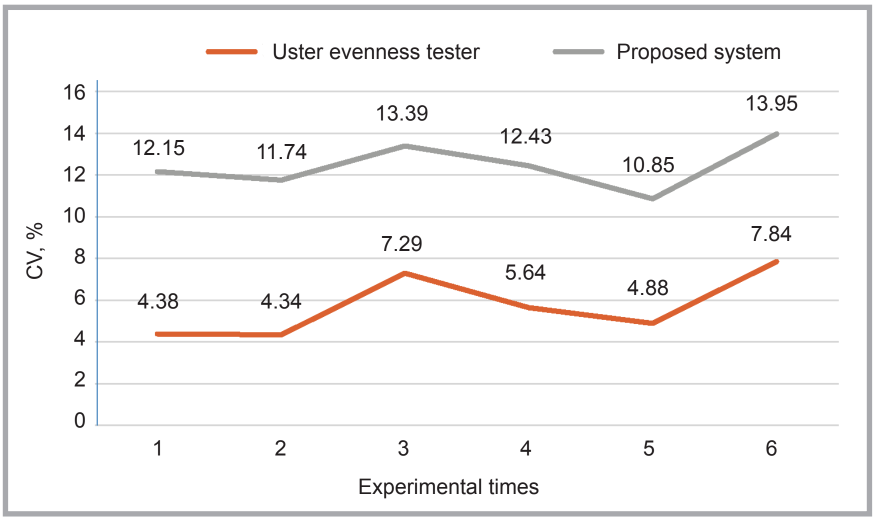

Figure 5. *Line charted results.*

Table 6. *Accuracy test results.*

Test methods groups	1	2	3	4	5	6
Uster evenness tester	4.38%	4.34%	7.29%	5.64%	4.88%	7.84%
System proposed	12.15%	11.74%	13.39%	12.43%	10.85%	13.96%

Table 7. *Correlation analysis results.*

Analysis indexes test methods		Uster evenness tester	System proposed
Uster evenness tester	Pearson correlation	1	0.874
	Significance (bilateral)		0.023
	N	6	6
System proposed	Pearson correlation	0.874	1
	Significance (bilateral)	0.023	
	N	6	6

size 14 μm × 14 μm, yielding a detection accuracy of 14/6), which is higher than the Uster evenness tester's 8 mm; however, the trends were consistent. We analyzed the results shown in ***Table 6*** in SPSS for correlation analysis and to measure the degree of correlation, the results of which are provided in ***Table 7***.

The Pearson's correlation coefficient of our system and the Uster evenness tester was 0.874 and the significance (bilateral) was 0.023 < 0.05, which indicated that our system was significantly correlated with the Uster evenness tester at the 0.05 level.

Conslusions

In an effort to remedy the high cost and low precision of the Uster evenness tester, as well as the poor repeatability and objectivity of seriplane inspection, we established a raw silk evenness detection system that works based on accurate and intuitive image detection. The image acquisition segment of the system includes a CCD image sensor, telecentric lens, light source, raw silk winding device, and over feeding device; the image processing segment uses threshold segmentation and morphology processing operations. Images are captured by the image acquisition segment and processed by the image processing segment, and then the diameters of the silk samples are extracted and their CVs calculated in Halcon software to determine evenness. Finally, Three experiments were conducted to verify the stability, repeatability and accuracy of the system proposed. Experimental results showed that eminent stability, repeatability and accuracy were acquired by the system.

In the future, we plan to perfect and extend the functions of this system as per the inspection of raw silk defects in addition to evenness. We hope that this system, once fully developed, will facilitate the effective and efficient characterisation of raw silk appearance, quality, and value.

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