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Measuring Thread Densities of Woven Fabric Using the Fourier Transform

Abstract

To replace time-consuming and lab-intensive of manual inspection, a Fourier transform is proposed to detect the thread densities of woven fabric in this paper. First, theories of the Fourier transform, yarn image reconstruction and the threshold method are introduced. Then the steps of fabric image acquisition, the Fourier transform of the fabric image, feature analysis in the frequency domain, image construction of fabric yarns, and threshold processing are analysed. Lastly, after locating and counting the yarns in the fabric segmentation results, thread densities of the woven fabric are calculated. The experimental results prove that the method proposed can detect the thread densities of woven fabric correctly and it can be used to replace the current manual analysis.

Key words: thread density, woven fabric, Fourier transform, threshold segmentation, image reconstruction.

research focuses on the first step. The main methods for inspecting the densities of woven fabric with image analysis used so far can be divided into two categories: frequency-domain analysis methods and time-domain analysis methods.

A woven fabric image is a typical period texture formed by warp and weft yarns. It can be transformed into a frequency domain with a Fourier transform. The peaks representing the frequency of periodic elements are located in the power spectrum to calculate the fabric density [1 - 7]. The peaks corresponding to the periodic information of the warp and weft arrangement were used to reconstruct an image of woven fabric. A reconstructed image containing only warp or weft yarns is adopted to recognise the density of the woven fabric [8 - 10]. Some researchers have tried to use the wavelet transform to reconstruct a fabric image along the warp and weft directions and then inspect the density of the woven fabric density [11 - 13].

In a reflective image of woven fabric, the gray value of pixels in the yarn is larger than the gray value of pixels in the interstices of the yarns. With grey projection, warp and weft yarns in the reflective image can be located [14 - 19]. In the transmitted fabric images, the interstices of the yarns can be located using the grey-projection method [20]. The gray co-occurrence matrix is used to recognise the woven fabric density [21].

The methods for inspecting the density of woven fabric have been described in many references, but there are few reports about the actual system. The actual fabrics are more complicated than those used in the research, such as the uneven-

ness of the yarn, the skew of the warp and weft yarn, and the hairiness of yarn. In this paper a measurement system is constructed for inspecting the thread densities of woven fabric. Fourier transform analysis is proposed to realise the automatic inspection of the thread density of woven fabric.

The rest of this paper is organised as follows: The image acquisition method, Fourier transform analysis and the threshold segmentation method are described in section "Methods"; the experimental results are discussed and analysed in section "Results and discussion", and the last section summarises the content of this paper.

Methods

Image acquisition

The objective of this paper is to obtain a real-time inspection system for the density of woven fabric. A flat scanner can capture a fabric image with high resolution, but the acquisition model is not suitable for real-time processing [22]. A CCD camera can be used to construct a real-time image processing system. But the magnification of the simple lens of a CCD camera is not large enough to distinguish the yarns in the fabric. A digital microscope is chosen as the hardware for image acquisition. The magnification of the microscope used is 10 - 40 and the highest resolution of the CCD camera in the digital microscope is about three-mega pixels. In the software system, when capturing a fabric image with the digital microscope, three kinds of resolution are provided for the operation: 512×384 pixels, 1024×768 pixels, and 2048×1536 pixels. The default magnification is 10 and the default resolution

Introduction

The thread density of woven fabric is one of the most important parameters for weaving in textile enterprises, which is currently measured with manual operations. One of the methods is to count the number of warp and weft yarns in a unit length with a textile analysis magnifying glass. The method is not only time-consuming and lab-intensive, but it cannot avoid the careless mistakes caused by operators who have been in service for a long time. The thread density detection results are influenced by the physical and mental conditions of the operators. Thus it is highly desirable to develop an automatic measuring system for the thread density of woven fabric.

Image analysis has been proved to be an efficient method of analysing the density of woven fabric. The work can be divided into two steps: The first step is to count the number of yarns in the fabric image and the second is to measure the physical dimensions of the fabric image. Generally the second step is done in the procedure of image acquisition. The current

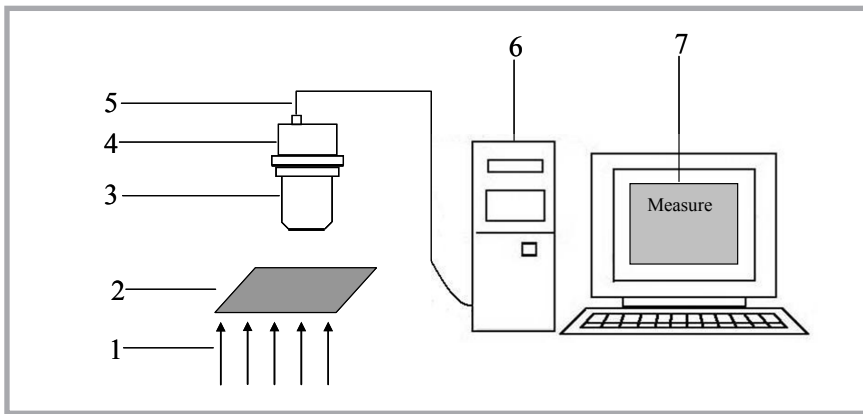


Figure 1. Structure of the fabric density measurement system; 1 - transmitted light, 2 - fabric sample, 3 - microscope, 4 - digital camera, 5 - usb data cable, 6 - computer, 7 - software).

512 × 384 pixels in the inspection system. The resolution of the image will be determined based on the weave structure parameters. If the yarns cannot be seen clearly with the default magnification and resolution, a bigger magnification and resolution can be chosen manually. The structure of the measurement system of the thread density of the woven fabric in the experiment is shown in **Figure 1**. The transmitted light source is used to illuminate the fabric sample. A USB data cable is used to transfer image data from the digital camera to the computer and the thread density of the woven fabric sample can be inspected with the software.

The size of the fabric sample used for inspecting the density is often small, not bigger than 10 × 10 cm. The fabric sample is stretched along different directions. The warp yarns are not perpendicular to the weft yarns, therefore the density of the warp and weft are inspected separately in the system. The group of yarns required to be measured are laid in the corresponding direction with more pixels. In the system, the default number is 512 pixels with an actual physical size of 1.2 cm. The actual magnification of

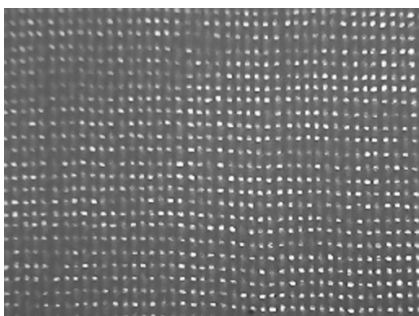


Figure 2. Transmitted image of plain fabric.

the digital microscope is confirmed after calibration.

If the fabric density is 100 threads/cm, one thread and the corresponding interstice occupy about 4.3 pixels with the default resolution. The resolution is enough to differentiate each yarn in the fabric. If the value of the thread density is larger than this, the operator can choose a bigger resolution in the software or adjust the magnification of the microscope to capture a fabric image with higher resolution.

Two kinds of illumination model are provided for inspecting the thread density of woven fabric in the system: transmitted and reflective. A default illumination model is transmitted and a light transmits through the interstices of yarns. The grey value of the pixels belonging to the interstice is larger than the grey value of the pixels in the yarn. **Figure 2** shows a plain fabric image captured by the system proposed with default parameters.

Three basic patterns of plain fabric, twill fabric and satin fabric are adopted to test the effectiveness of the inspecting system. Cotton fabrics with different yarn counts and density ranges are chosen to test the robustness of the detection system. Seven plain fabrics (P1 - P7), five twill fabrics (T1 - T5) and three satin fabrics (S1 - S3) are used in the experiment. **Figure 3** shows the typical fabrics of them with the parameter.

Fourier transform

The warp and weft yarns are woven together in the fabric and they cannot be counted in a unit length to calculate the density with the simple image-measurement method. The warp and weft yarns

should be separated by image analysis before inspecting the density.

The different period signals of the fabric image are mixed together in the time-domain, thus it is hard to use to analyse the texture directly. In the frequency-domain, the period of the yarn arrangement can be easily analysed. Therefore, in the system, a Fourier transform is carried out for the fabric image and then the thread density can be analysed in the Fourier frequency domain.

There are noise signals disturbing the periodic of the fabric image, such as uneven illumination and yarn hairiness. An image reconstructed with several peaks in the frequency-domain [1 - 10] neglected too many detail signals in the original image and the yarns will be not segmented correctly if the peaks are not correctly located. The robustness of the current algorithm for detecting density cannot meet the need of the inspecting system. To solve the problems above, the regions

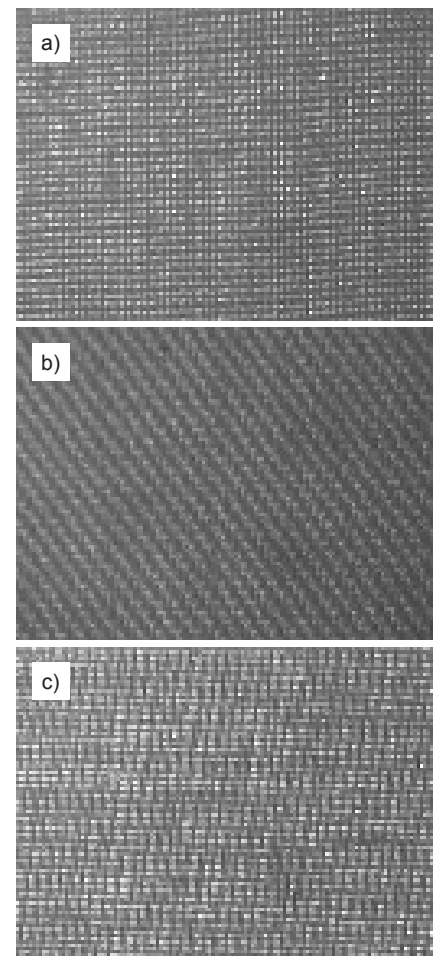


Figure 3. Typical fabrics used in the experiment; a) plain fabric (14.6 tex × 14.6 tex), b) twill fabric (18.2 tex × 27.8 tex), c) satin fabric (7.3 tex × 7.3 tex).

(not just several peaks) corresponding to the periodic of warp and weft yarns in the amplitude spectrum of the Fourier transform are chosen to reconstruct the fabric image. The thread densities of warp and weft yarns are inspected in the reconstructed image.

As a two-dimension discrete array can be seen in the gray-scale image, the two-dimension discrete (2D) Fourier transform is selected to analyse the woven fabric image. The fabric image and corresponding Fourier transform results are defined as $f(x, y)$ and $F(u, v)$, where x, y are the coordinate variables in the time domain and u, v are the coordinate variables in the frequency domain. The amplitude spectrum $M(u, v)$ of the Fourier transform can be calculated as:

$$M(u, v) = \sqrt{R^2(u, v) + I^2(u, v)} \quad (1)$$

where, $R(u, v)$ is the real part and $I(u, v)$ the imaginary part.

To observe the result of the Fourier transform conveniently, the amplitude spectrum $M(u, v)$ is shown as a grey image. The numerical range of $M(u, v)$ is too large to use a simple linear transform to change $M(u, v)$ into the value range of the grey image scale (0 - 255, 256 grey levels).

Therefore the Log transform is adopted to narrow the numerical range of $M(u, v)$ to show it as an image. The value "1" is added to the amplitude spectrum to ensure that the results of the log function is a positive number. The amplitude spectrum after the Log transform is defined as $StreM(u, v)$, as in **Equation 2**.

$$StreM(u, v) = \log_2[M(u, v) + 1] \quad (2)$$

After narrowing the numerical range, a linear transform is used to adjust the amplitude value into the range of [0, 255], as shown in **Equation 3**.

$$TM(u, v) = \text{floor} \left[\frac{StreM(u, v) - T_{\min}}{T_{\max} - T_{\min}} \times 255 + 0.5 \right] \quad (3)$$

where, $TM(u, v)$ is the amplitude spectrum after the linear transform; T_{\max} and T_{\min} represent the maximum and minimum values of $StreM(u, v)$, and $\text{floor}(\)$ represents the rounded down function.

The peaks corresponding to periodic information of the fabric are in the low frequency regions, which are on the borderlines of the amplitude spectrum. It is not convenient to observe the fabric fea-

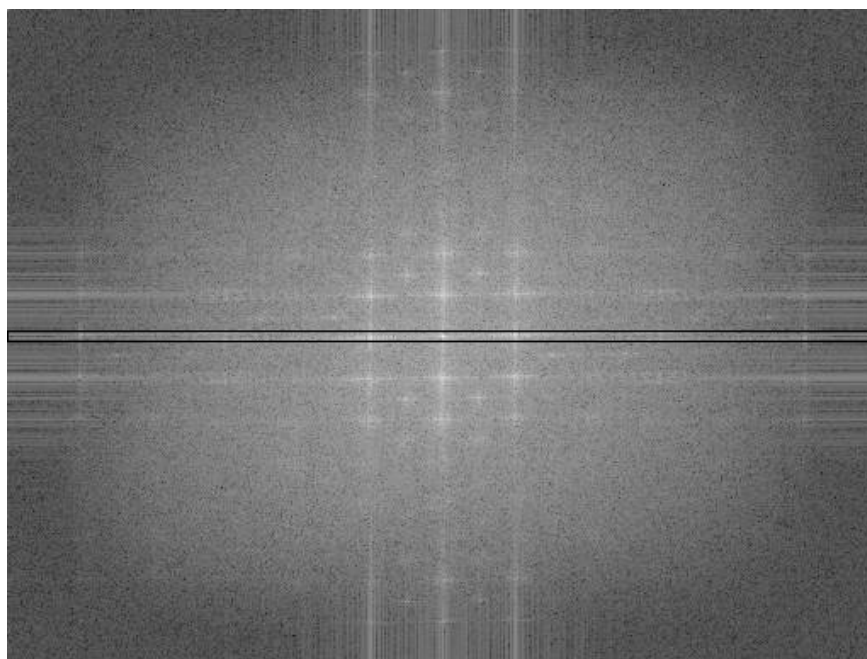


Figure 4. Amplitude spectrum of fabric image.

tures. Thus the centre of the image is then defined as the origin of the coordinate, and the x-axis and y-axis are set up along the horizontal and vertical directions in the inspection system. The first and third quadrants, and the second and fourth quadrants are interchanged, respectively, which is called a frequency shift. The low frequency is then shifted into the centre and the high frequency into the boundary of the amplitude spectrum.

The result of the inverse Fourier transform is used to reconstruct the fabric image. The amplitude value of the inverse transform is obtained as **Equation 1** and then changed into [0, 255] **Equations 2** and **3**. In the reconstructed image, the weft yarns are removed, while the warp yarns are retained, or vice versa. Some image analysis methods are used to locate the yarns and count the number of yarns. The thread densities are then calculated.

The 2D fast Fourier transform is adopted to process a woven fabric image, shown in **Figure 2**, and the amplitude spectrum is then obtained as shown in **Figure 4**. Characteristic peaks corresponding to the periodic of warp and weft yarns are in the centre. The values of the peaks are larger than surrounding points, but there are some subordinate bright points around the peaks, which will be removed with a simple peak filter. Many detail signals of the yarns are neglected as they are repre-

sented by these subordinate bright points in the frequency domain.

The number of yarns in the fabric image can be calculated with the relation between the peaks and direction component [23], and then the density of the warp and weft can be inspected; but it is hard to discriminate the yarns in the boundary of the image. The density cannot be inspected with high precision. The feature region containing the peaks is chosen to reconstruct the fabric image with warp or weft yarns. The periodic signals of warp yarns are represented as a horizontal bright line along the centre of the amplitude spectrum and the periodic signals of weft yarns are represented as a vertical bright line along the centre. The region containing horizontal or vertical bright lines is chosen to reconstruct the warp or weft yarns with frequency signals.

Image segmentation

The grey-projection method can be used to locate warp or weft yarns, but it is easily influenced by the straight state of the yarns. In the reconstructed image, there are significant differences in the gray values of the yarns and interstices. The threshold segmentation method is used to separate the yarns from the background.

When capturing the fabric image, light sources are used to illuminate the fabric. This results in a brightness difference between the centre region and marginal region in the image. It is hard to segment

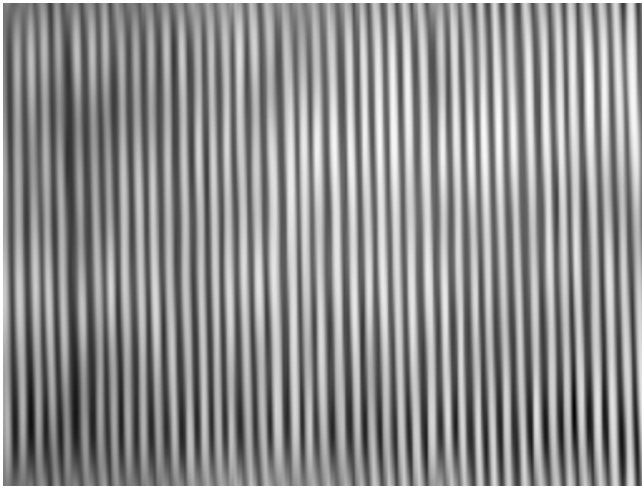


Figure 5. Reconstructed signals of warp yarns.

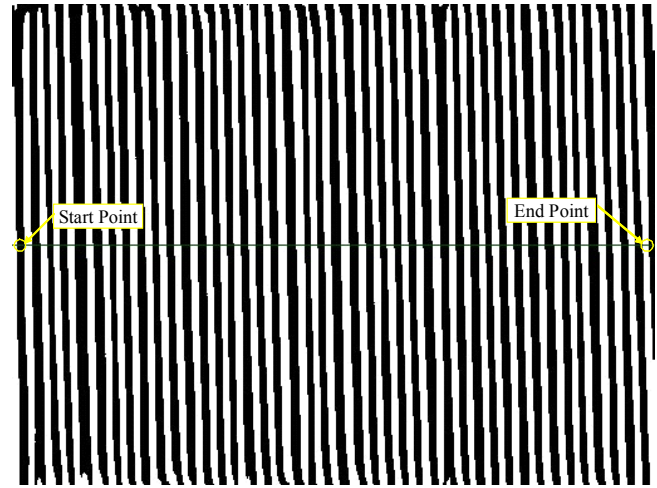


Figure 6. Image of warp yarns after threshold process.

all the yarns in the fabric image with the global threshold method. To eliminate the unevenness of the illumination, the local adaptive threshold method is used to segment the warp or weft yarns in the reconstructed fabric images.

There are two main factors for the local adaptive threshold method: One is the local window size and the other is the threshold method used in the local window. The choice of window size is relative to the size of the single yarn diameter. The local window should include the yarn and interstices. The size of the window should, at least, be larger than the yarn diameter. The pixel number in the yarn is determined by the magnification. In the experiment, 32×32 pixel is set as the default local window size. The size of the local window changes with the magnification of the fabric image.

The illumination in the local window can be considered as even. Niblack's threshold method [22] is selected to process the pixels in the local window. The threshold value can be obtained as *Equation 4*.

$$T = u + k \cdot \sigma \quad (4)$$

where, u is the mean value of the pixels in the local window and σ is the standard deviation value of the pixels in the local window; k is a constant value which will be determined in the experiment.

The fabric image captured in the experiment is a kind of transmitted image, thus the gray values of the pixels in the yarn are lower than those in the interstice. In the threshold process, the pixels with gray values greater than the threshold

value T are in the interstice and other pixels are in the yarn.

Results and discussion

Fourier filtering and fabric image reconstruction

The reconstruction of warp yarns is taken as an example to describe the procedures. A horizontal band-filter around the horizontal bright lines is selected to filter the frequency signals. The filtered signals are used to reconstruct a fabric image with an inverse Fourier transform.

To ensure the peaks corresponding to the periodic of the warp yarns are included in the selected region, the frequency signals smaller than three pixels, apart from those from the center horizontal line, are all chosen to form the reconstructed frequency filter band.

A filter template $TP(u, v)$ containing 0 and 1 is established according to the image size captured while designing the system. To retain the frequency signals, the values of the same position in the template are set as 1. Otherwise the values of the pixels in the template are set as 0. When constructing the template, the horizontal line along the direct component and the horizontal lines floating three pixels up and down are chosen as the filtering region.

The result of the Fourier transform is dot-multiplied with the template, and then the feature frequency band $InvF(u, v)$ for reconstructing an image of warp yarns can be obtained as shown in *Equation 5*.

$$InvF(u, v) = F(u, v) \times TP(u, v) \quad (5)$$

The filtered amplitude spectrum is shown as a rectangle labelled with a black line in *Figure 4*. From the figure, it can be seen that the peaks corresponding to the periodic of warp yarns are included in the selected frequency band. The image can be reconstructed with the filtered frequency signals and warp yarns separated from the weft yarns can be obtained.

The reconstruction result of warp yarns is obtained as shown in *Figure 4*. From the figure it can be seen that the signals of weft yarns are removed while the signals of warp yarns are retained. In this image, the number of warp yarns can be easily counted. The positions and state of the warp yarns in the reconstruction result are still same as in the original image, shown *Figure 2*. The light intensity of yarns in *Figure 5* is same as in the original image. The bright regions in the figure represent interstices between the yarns, while the dark regions represent the warp yarns.

Woven fabric density inspection

After obtaining the reconstructed image of warp yarns, some image processing methods can be used to count the number of warp yarns to measure the warp density. The positions of the warps should be located before counting the yarns. As the gray values between the yarns and interstices are significantly different, the threshold method is adopted to process the reconstructed image to locate the yarns and interstices. Local Niblack's threshold method is used to threshold the image to locate the yarns. The optimal value k is chosen as 0.2 with many experiments. The threshold results are shown in *Figure 6*.

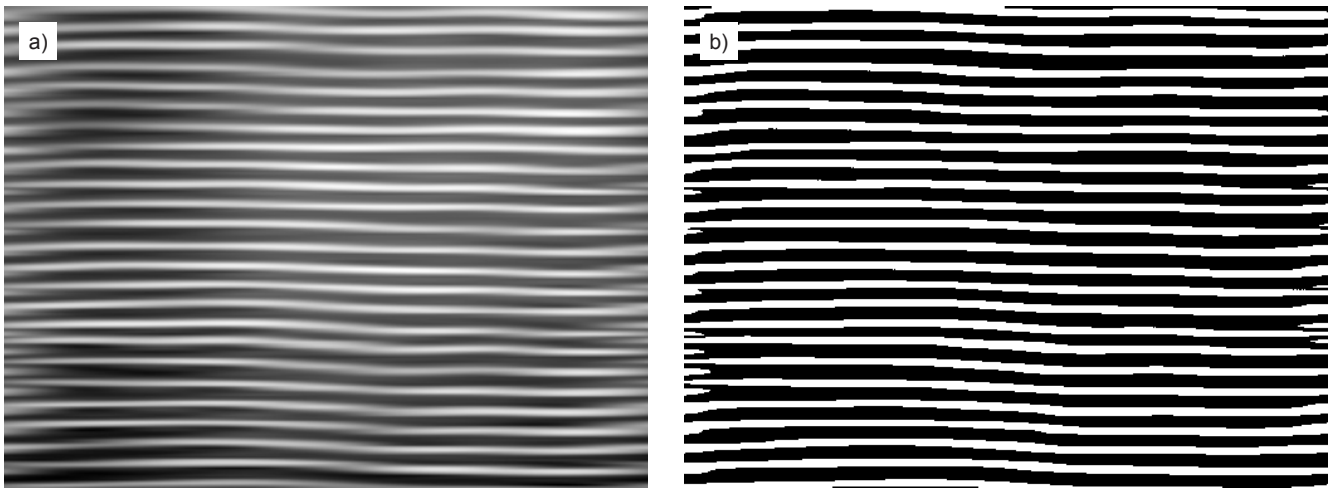


Figure 7. Inspection of weft density; a) reconstructed image of weft yarns, b) binary image of weft yarns.

The black pixels in **Figure 6** represent the warp yarns while the white pixels show the interstices. To count the number of yarns, the centre horizontal line of the image is chosen as the measurement standard line as shown in **Figure 6**. The pixels in the standard line are traversed from left to right. The number of yarns along the standard line is then counted. A whole yarn in the image includes two parts: the yarn and the interstice. When one yarn and the corresponding interstice are traversed, the number of yarns is added to by one.

The start pixels in the standard line belong to the boundary yarn or interstice. The pixel which has the opposite grey value to the first pixel (from the left) in the standard line is selected as the start point. It means that if the first pixel is a white point, the first black pixel during the traversal is chosen as the start point for the density measurement, and vice versa.

The pixel belonging to the last whole yarn or interstice opposite the start point is selected as the end point. For example, in **Figure 6** the start point is a black pixel which is chosen as the start pixel of the first yarn in the left, labeled as “Start Point” in the figure. The white pixel belonging to the last interstice on the right of the image is chosen as the end point, labelled as “End Point”.

After obtaining the start and end points in the binary image, the density can be measured by counting the number of yarns during the traversing of the standard line. In the standard line, there are only two kinds of grey signal: 0 and 1. When the signals are alternated, the current pixel is the alternative point of the yarn and interstice. If the grey value of

the alternative point is same as the start point, a new yarn is considered to be found. Based on this method, all yarns can be found.

Inspection results of density

After obtaining the number of yarns, with the position of start point and end point, the density of warp yarns can be calculated with the magnification of the captured image. The calculation method is carried out as **Equation 6**.

$$D_{warp} = \frac{N}{(EP - SP + 1) \times Scale} \quad (6)$$

where, D_{warp} is the density of warp yarns in threads/cm, N the number of warp yarns, EP the coordinate of the end point, SP the coordinate of the start point, and $Scale$ is the magnification value of the fabric image captured in cm/pixel.

In this example, N is 42 threads, EP 506 and SP 4, and $Scale$ is 0.002363 cm/pix-

el; D_{warp} is calculated with the result of 35.3 threads/cm.

The density of weft yarns can be measured with a similar method. The weft yarns separating from the warp yarns are reconstructed with the selected frequency signals in **Figure 7.a**, and the image after threshold processing is shown in **Figure 7.b**. The number of weft yarns is counted and the weft density automatically calculated according to **Equation 6**. The weft density of this fabric image is 27.0 threads/cm.

In the measurement system, the density of weft yarns is inspected by rotating the sample 90° to get a larger physical size. The density of warp and weft yarns is measured ten times in all. The mean value is automatically calculated and adopted as the final measurement result.

Table 1. Comparison of detection results of fabric density from automatic and manual methods.

Fabric sample	Warp density, threads/cm		Weft density, threads/cm		Measurement error, %	
	automatic	manual	automatic	manual	warp	weft
P1	53.7	53.5	37.2	37.0	0.37	0.54
P2	56.5	56.5	38.5	38.5	0.00	0.00
P3	61.1	61.0	39.0	39.0	0.16	0.00
P4	41.3	41.5	18.1	18.0	0.48	0.56
P5	65.6	65.5	39.3	39.5	0.15	0.51
P6	42.5	42.5	30.9	31.0	0.00	0.32
P7	47.2	47.0	21.6	21.5	0.43	0.47
T1	61.8	62.0	27.3	27.5	0.32	0.73
T2	48.4	48.5	36.3	36.0	0.21	0.83
T3	65.6	65.5	35.7	35.5	0.15	0.56
T4	50.2	50.0	21.5	21.5	0.40	0.00
T5	54.2	54.0	20.7	20.5	0.37	0.98
S1	99.6	99.5	78.3	78.5	0.10	0.25
S2	76.2	76.0	42.4	42.5	0.26	0.24
S3	87.9	88.0	44.7	44.5	0.11	0.45

The fabrics used in the experiment are all automatically measured with the method proposed. Inspection results for the density of warp and weft yarns are listed in **Table 1** (see page 39). The densities of these fabrics are measurement manually with the help of a textile magnifying-glass. Manual detection results are also listed in **Table 1**.

Measurement error is calculated to evaluate the inspection results of the automatic and manual methods. The error is calculated with **Equation 7**.

$$\text{Error}\% = \frac{|D_A - D_M|}{D_M} \times 100\% \quad (7)$$

where, D_A is the automatic detection result, and D_M the manual detection result.

Comparing the automatic detection results to those of manual detection, it can be seen that the results are almost the same, with a maximum error of 0.98% (warp density of fabric sample T5). The error mainly results from the different measurement region selected for density detection. The boundary of yarn in the margin of the measurement region is not the same in the measurement. From the result, it is concluded that automatic density detection can be used to replace the current manual density detection method. The system proposed can achieve the aim of saving labour and reducing the lab intensity of the operators.

With our measurement system proposed, the thread densities of woven fabrics can be inspected automatically. A reconstruction image of yarns is used to help the operator determine the orientation of the fabric. The operator just needs to select ten different regions in the fabric to obtain the final measurement result of fabric density. The densities of a fabric sample can be inspected within one minute with the system proposed, which is much faster and more convenient than the traditional manual method.

Conclusions

In this paper, image analysis is proposed to realise automatic density detection for woven fabrics. A fabric image is captured with a digital microscope. The relation between the time and frequency domain of the fabric image is discussed and a frequency band is chosen to reconstruct fabric images including only the warp or weft. Threshold segmentation is used to

locate the yarns and then their number is counted to automatically inspect the density of warp and weft yarns. Experimental results proved that the method proposed can realise the precise measurement of woven fabric density. The automatic inspection method can replace the current manual analysis method with human vision. Based on the theory proposed, an automatic density detection system for woven fabrics can be constructed successfully.

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