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Automatic Inspection of Woven Fabric Density of Solid Colour Fabric Density by the Hough Transform

Abstract
When analysing the colourcolours in woven fabrics images, the fabrics are suggested to be divided into three categories: solid colour fabrics, single-system-mélange colour fabrics and double-system-mélange colour fabrics. Corresponding to the classification, the inspection of woven fabric density can be also divided into three stages. A method of inspecting the density of solid colourcolour fabrics is discussed in detail in this study. The Hough transform is used to detect the skew angles of warp and weft yarns, and then the pixels in the fabric image are projected along the skew-direction. Warp and weft yarns can be segmented successfully by locating the true minimum values which indicate the interstices between the yarns. The density of solid colourcolour fabric can be inspected by counting the yarns in a unit length in the fabric image.

Key words: *Hough transform, fabric image, solid colour fabric, density, warp, weft, model.*

Introduction

Traditional methods of measuring woven fabric density are mainly based on manual operations. One of these methods is to count the number of warp and weft yarns in a unit length with a textile analysis magnifying glass. These methods are not only time-consuming and lab-intensive, but also they cannot avoid careless mistakes committed by workers who have been in service for a long time. The detection results are often influenced by the mental and physical condition of the inspectors. Thus, it is highly desirable to develop an automatic counting system for fabric density. Image analysis has been proved to be an efficient method of analysing fabric density. The main method used so far is the Fourier transform technique [1 - 2]. The main principle is to find the peaks in the power spectrum which represent the frequency of periodic elements in the time domain image. As warp and weft yarns form periodic texture in the fabric image, the number of yarns can be recognised by locating the peaks in the frequency domain image. These methods are limited to solid woven fabric and cannot be applied to colour fabrics. It is hard to inspect the density of colour fabrics in the frequency domain because the colour pattern is combined with the power spectrum formed by other textures in the fabric.

The co-occurrence matrix has been proposed to inspect fabric density [3]. The experiment showed that the inspection accuracy rate for plain weaves is far better than that for twill or satin weaves. Moreover, it is impossible to use this method to measure the density of colour fabrics. We have used the gray projection method to inspect fabric density in previous research [4]. At that time we discussed white fabrics only. We need to do more research on colour fabrics in this study.

Besides the methods mentioned above, some other researchers [5 - 8] have also conducted investigations related to fabric density when they studied other subjects. However, the theories proposed mainly focus on white fabric; during the process for this, the fabric should be laid in a position without skew. Weft yarns are laid in a horizontal direction, while warp yarns should be in a vertical direction in the fabric image. The algorithm demands a high image acquisition. However, during the process of capturing a fabric image, the skew of the fabric cannot be completely avoided. We have proposed a method for fabric image skew rectification [9], but at that time we were devoted to rectifying the skew brought about by the position in which the fabric was laid during the capture process. The warps were believed to be perpendicular to the wefts in the fabric. The skew of the fabric could be rectified by rotating the wefts to place them in horizontal direction. In fact, as shown in ***Figure 1***, the wefts may not be perpendicular to the warps. In this situation, the skew of the fabric cannot be rectified by rotating one group of yarns. As the wefts and warps can not be laid in a vertical and horizontal direction at the same time, the method mentioned above can not detect the weft and warp density simultaneously. Without a doubt, the warp and weft density can be individually detected by the method mentioned. However, it is not convenient to detect

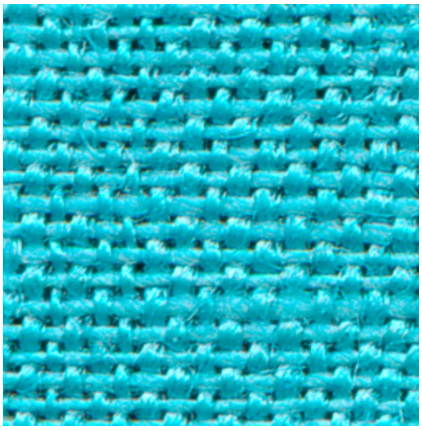


Figure 1. Reflective image of solid colour fabrics.

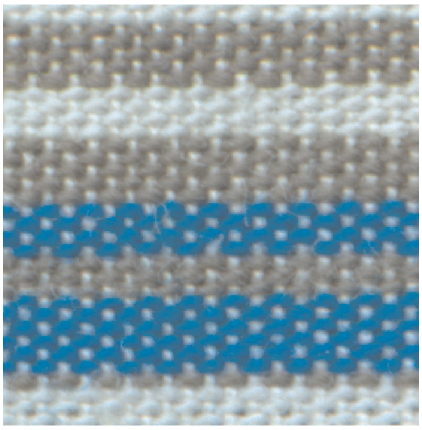


Figure 2. Image of single-system-mélange colour fabric.

Figure 3. Image of double-system- mélange colour fabric.

the fabric density by rotating the image twice. Therefore, there is a great need to develop a new method of detecting the density of fabric with skew yarns.

To inspect the density of different fabrics, we investigated the actual fabrics in the experiment and proposed to divide the fabrics into three categories according to the colours in the fabric image.

1) Solid colour fabrics. There is just one kind of colour yarn in this fabric, as shown in ***Figure 1***. White fabrics, which have already been discussed, are assigned to this category.
2) Single-system-mélange colour fabrics. There are more than two kinds of colour yarns in this fabric. But one group of yarns, wefts or warps are constituted by one kind of colour yarn. ***Figure 2*** shows one sample of this fabric. The warps are all white yarns, while the wefts are composed of three kinds of yarns with different colours.
3) Double-system-mélange colour fabrics. These are also composed of more than two kinds of colour yarns, but they are different from single-system-mélange colour fabric. Both wefts and warps are composed of more than two kinds of colour yarns. ***Figure 3*** shows one sample fabric compared with the two other fabrics above. This category of fabrics is the most complicated, and it is difficult to detect the density of wefts and warps.

Having categorised the fabrics, we discussed methods of detecting fabric density with the three steps in the experiment. Moreover, the entire system will be created by analysing different kinds of fabrics. In this study, the first category, solid colour fabrics are discussed. The Gray-projection method, discussed in a previous study [9], is improved to cater for colour fabrics with skew yarns.

Hough transform

It is not convenient to detect the warp and weft density at the same time when the fabric is composed of skew yarns. To solve this problem, the skews of warps and wefts were detected in the experiment, and then the fabric density was measured automatically. The Hough transform, first proposed by Hough in 1962 [10], can detect lines in an image automatically without previous experience. In this study, it is used to detect the skew angles of warps and wefts. In the polar coordinate system [11], the line concerned, shown in ***Figure 4***, can be expressed by:

$$s = x\cos\theta + y\sin\theta \qquad (1)$$

With Equation 1 the points in an image space can be changed into a parameter space by the Hough transform. As shown in ***Figure 5***, the s, θ parameter space can be divided into a number of small blocks, each one indicating a straight line. Here H and W denote the height and width of the image, respectively. To detect lines in the image space, it is simply required to search all the pixels concerned in the image and calculate all corresponding s, θ pairs. Straight lines in the image space can be found by searching for the peaks in such a parameter space.

The algorithm of the Hough transform can be found [12] using the following steps:

1) Define the increments of s and θ: Δs and $\Delta\theta$.
2) For each pixel concerned, calculate the corresponding s value for each θ in the parameter space by Equation 1.
3) Accumulate s, θ pairs for each block and find the line which is defined by

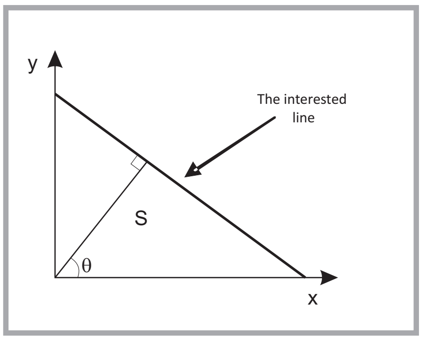


Figure 4. Theory of Hough transform.

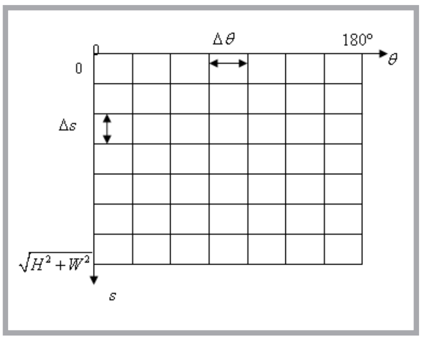


Figure 5. s, θ parameter space.

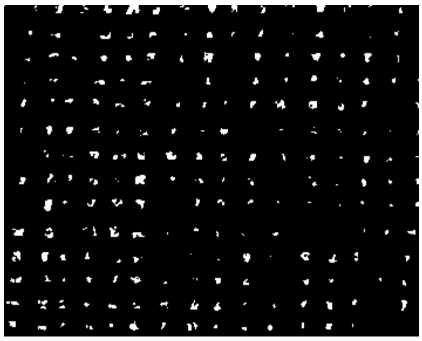


Figure 6. Fabric image after threshold processing.

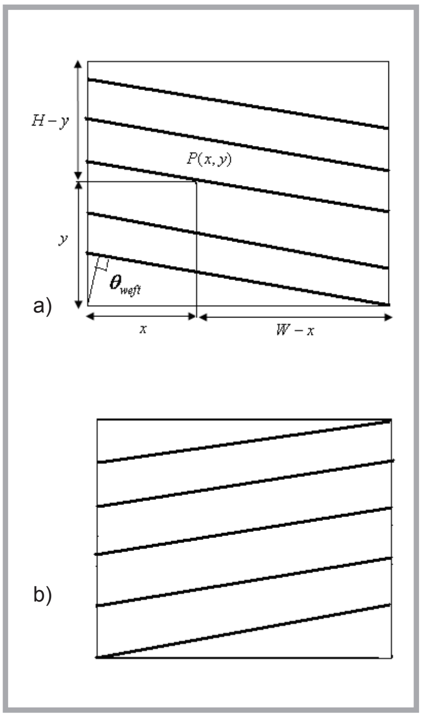


Figure 7. Fabric models with skew wefts; a) slanting to the left, b) slanting to the right.

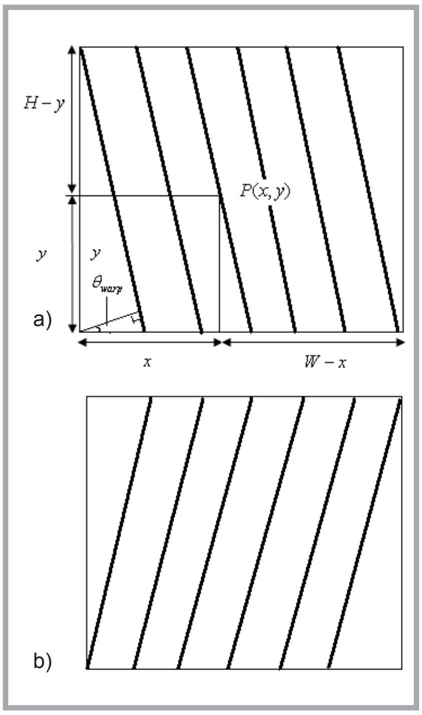


Figure 8. Fabric models with skew warps; a) slanting down, b) slanting up.

the block with a maximum value in a certain angle range.

Detecting the skew of yarns

Image acquisition

A Microtek flat scanner is used to capture a reflective image of solid colour fabric in the RGB mode. The resolution is set as 1200DPI. Mélange colour fabrics will be discussed in the future. We digitise fabric images using the full-colour mode (RGB Mode). The region captured should be chosen far from the edge of the fabric, and the surface of fabric should be clearly visible.

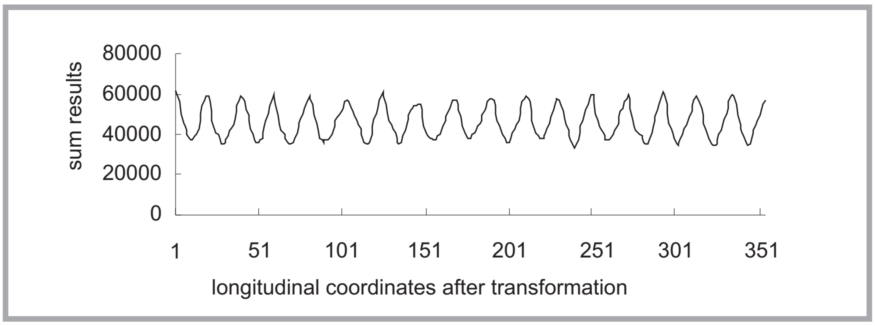


***Figure 9.** Sum results of the gray level along the horizontal direction after coordinate transformation.*

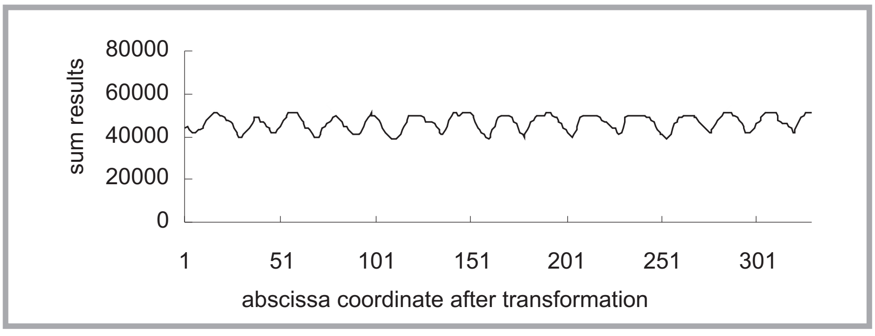


***Figure 10.** Sum results of the gray level along the vertical direction after coordinate transformation.*

Threshold processing

The Hough transform needs too much computing time in the traditional method. To reduce the calculation, some preprocesses should be conducted before detecting lines. As mentioned above, the aim of the Hough transform in this study is to determine the skew angles of yarns. It is obvious that the interstices between the yarns are parallel to the yarns in the fabric. For this reason, the fabric image can first undergo the threshold process to remove most of the pixels, leaving just some which represent the locations of interstices in the fabric image. The Hough transform will be implemented for these pixels, and it will still be possible to detect the skew angles.

The threshold value can be found as follows:

1) Convert the fabric image from the RGB mode to the gray (256 levels) mode, and then accumulate the pixels for each level in the image. Statistical results, Gray[256], can then be obtained.
2) The threshold value can be calculated by:

$$Threshold = i(\sum_{0}^{i} Gray[i] > H \times W \times 5\%) \quad (2)$$

About 5% of pixels in the fabric image will be kept after the threshold process. The result of threshold processing for the fabric image in ***Figure 1*** is shown in ***Figure 6***. The Hough transform will be applied to white pixels in the image.

Detecting the skew angles

To detect the skew angles of weft and warp yarns in the fabric, the Hough transform is carried out for the fabric image after threshold processing. During the image acquisition process, the fabric is placed in a position to avoid skew. The skew angle is considered to be no more than 20°. To detect the skew of weft yarns, θ is set within the range 80°, 100°. When detecting the skew of warp yarns, θ is set within the ranges 0°, 10° and 170°, 180°. The skew angles of warps and wefts, θ_{warps} and θ_{wefts}, can be detected with Hough transform ($\Delta s = 1$, $\Delta\theta = 0.5°$).

Detecting the fabric density

Model of fabric with skew wefts

In the ideal fabric image used in this paper, the warps are in a vertical direction, while the wefts are in a horizontal direction. In the reflection image it is clear that the pixels in the interstices and intersection between yarns have lower gray levels. The pixels around the center of the warp and weft yarns possess higher gray levels. To locate the wefts and warps, one simply has to sum the gray levels of the pixels along the same horizontal and vertical pixel lines over the entire fabric image. The interstices between yarns and yarn center-lines exhibit the lowest and highest gray-level sums. But if the yarns are not in a horizontal or vertical direction, it means that the yarns have skew, and hence we cannot determine the position of yarns by summing the gray levels in the horizontal or vertical line. ***Figure 7*** shows a weft model with skew in the fabric. To put it simply, the warps are neglected.

In this model we cannot use the traditional method to detect the weft density. To locate weft yarns in the model, we sum the gray-level of pixels in the skew-direction, which means that the gray levels of pixels in the actual yarns are summed. To achieve this, the coordinates of pixels in the fabric image should first be transformed. The transform principle is shown in ***Figure 7.a***, $P(x, y)$ being the original coordinate of one pixel point in the image, and $P(x_0, y_0)$ - the coordinate after transformation. The coordinate transforms can be defined by:

$$\begin{cases} x_0 = x \\ y_0 = y - (W - x) \times \tan(\frac{\pi}{2} - \theta_{weft}) \end{cases} \quad (3)$$

Similar to the wefts, in an ideal fabric the warps are in a vertical direction. ***Figure 8*** shows fabric models with skew warps. To put it simply, the wefts are neglected. As with the weft segmentation, the coordinates of pixels in the fabric image should be transformed. The theory is shown in ***Figure 8.a***. We assume $P(x, y)$ to be the original coordinate of one pixel point in the image, and $P(x_0, y_0)$ - the coordinate after transformation. The coordinate transforms for fabric with skew warps can be defined by:

$$\begin{cases} x_0 = x - (H - y) \times \tan\theta_{warp} \\ y_0 = y \end{cases} \quad (4)$$

Gray-projection method

In order to get gray information from a full colour fabric image, Equation 5 is used to obtain the gray value of each pixel.

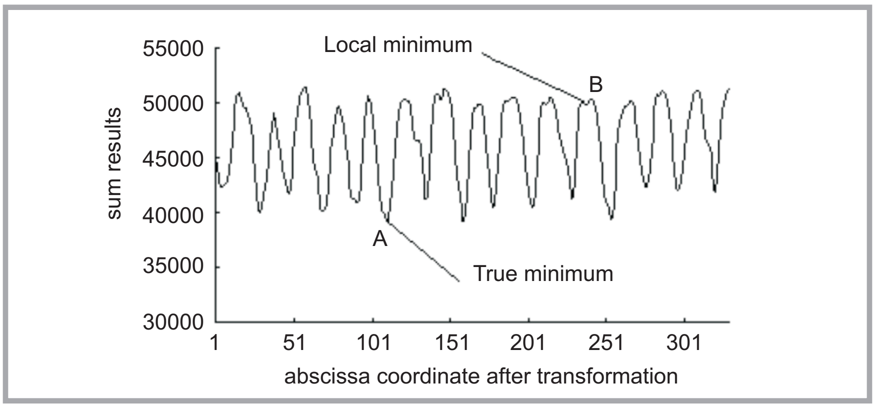


Figure 11. *Two kinds of minimum values.*

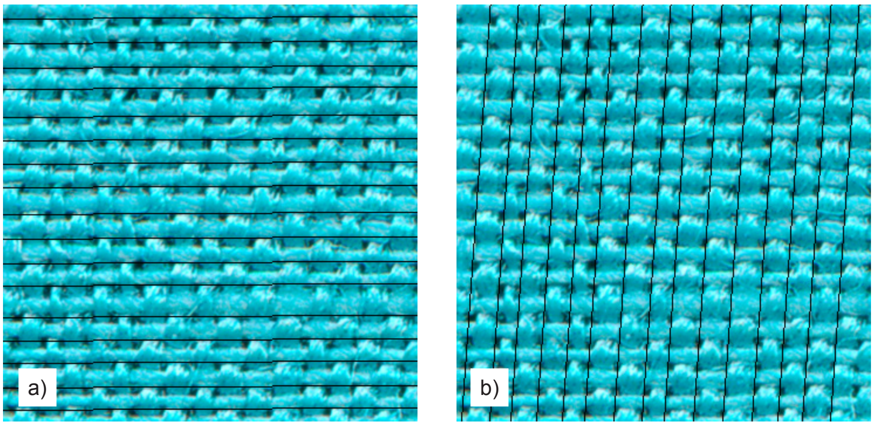


Figure 12. *Yarn segmentation results; a) weft segmentation, b) warp segmentation.*

$$Gray = 0.587 \times R + 0.587 \times G + 0.114 \times B \quad (5)$$

where: R, G, B represent the three components in the RGB colour model.

After coordinate transformation, the gray levels are first summed along the same horizontal direction, which means that the pixels in the wefts and interstices between wefts are summed respectively. Take the fabric shown in ***Figure 1*** as an example, the sum results for which are shown in ***Figure 9***. Weft yarns lie in a position where the local maximum gray-level sums occur, whereas the interstices are located in positions where the local minimum gray-level sums occur. Based on the locations of the yarn and interstices, the wefts can be segmented successfully.

The gray levels along the same vertical direction are then summed, meaning that the pixels in the warps and the interstices between warps are summed, respectively. The fabric in ***Figure 1*** is as an example of this, the sum results of which are shown in ***Figure 10***. The warp yarns lie in a position where the local maximum gray-level sums occur, and the interstices are located in positions where local minimum gray-level sums occur. Based on the locations of the yarn and interstices, the warps can be also located successfully.

Locating the interstices

The wefts and warps can be segmented automatically by locating the minima in ***Figures 9*** and ***10***. If the point satisfies $G[i - 1] < G[i] < G[i + 1]$ in the ideal curve, $G[i]$ is considered as a minimum point, where $G[i - 1]$ and $G[i + 1]$ are the adjacent points of $G[i]$. However, from ***Figure 11*** it can be seen that the minimum points can be divided into two groups. Here, one group of points called the true minimum values are proportion to the interstices between yarns. Another group of minimum points are called the local minimum.

Local minimum points may be caused by an undulating weave structure or other reasons, but they do not represent the interstices, hence they should be eliminated from the results. A filter should be designed to remove these points. The filter used in the experiment is [0, 0, 1, 0, 0], meaning that only if the point is the mini-

Table 1. Yarn segmentation results for different fabric.

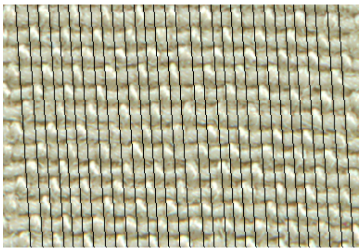
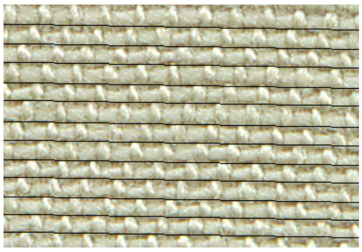
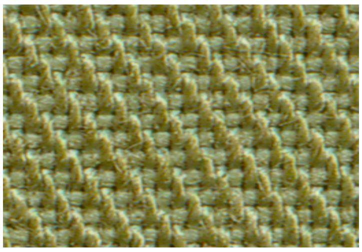
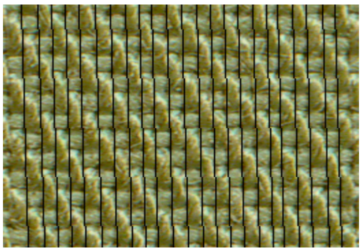
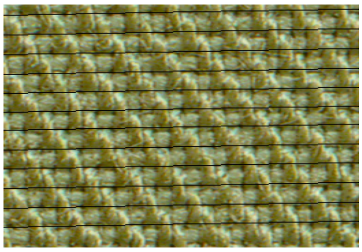
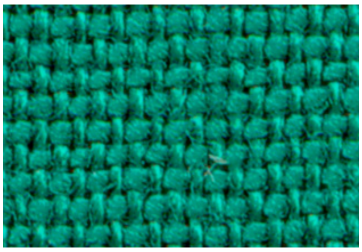
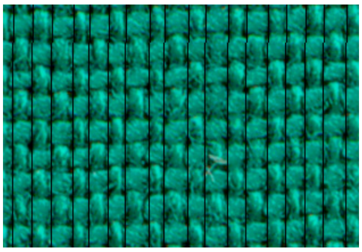
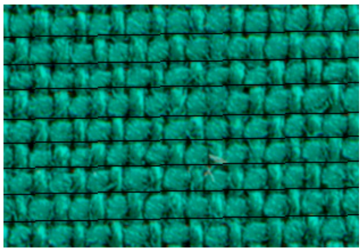
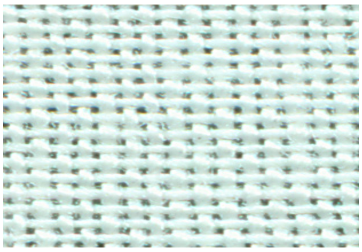
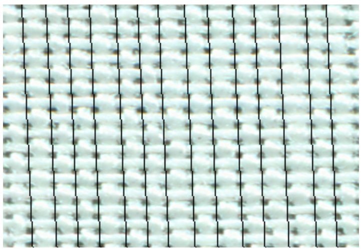
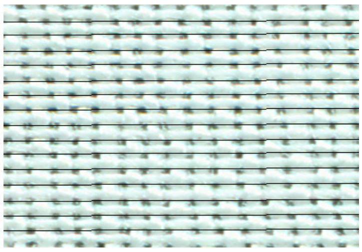
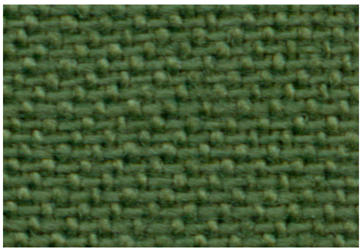
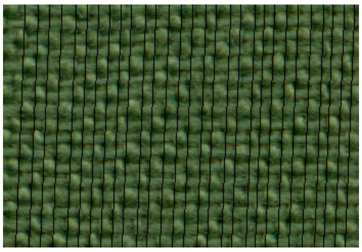
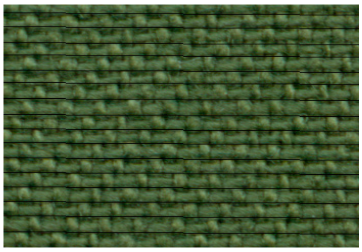
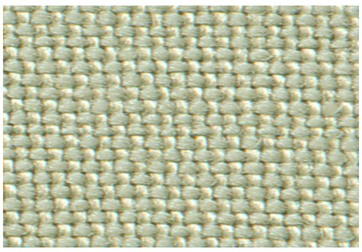
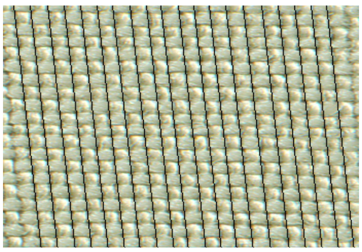
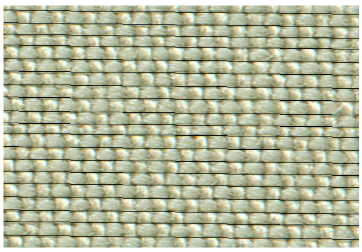
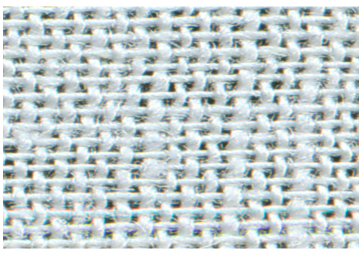
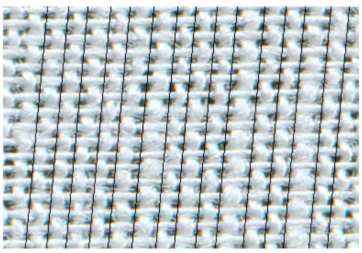
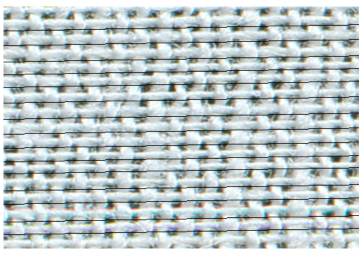
No.	Fabric reflection image	Warp segmentation results	Weft segmentation results
2			
3			
4			
5			
6			
7			
8			

Table 2. Fabric density measured automatically and manually; Sample 1 is the fabric shown in Figure 1, and samples 2 - 8 are the fabrics in Table 1.

Sample	Warp density, thd/inch		Weft density, thd/inch		Error, %	
	Automatically	Manually	Automatically	Manually	Warp	Weft
1	57.5	57.5	53.2	53.0	0.00	0.38
2	144.6	144.5	59.7	60.0	0.07	0.50
3	114.8	115.0	53.2	53.0	0.17	0.38
4	69.6	69.5	54.2	54.0	0.14	0.37
5	58.6	58.5	63.4	63.5	0.17	0.16
6	104.0	104.0	60.4	60.5	0.00	0.17
7	75.0	75.0	57.1	57.0	0.00	0.18
8	50.8	51.0	58.3	58.5	0.39	0.34

mum in the adjacent five points, is it then considered as a true minimum.

Warp and weft segmentation results

After removing the local minima, those in the curves in ***Figures 9*** and ***10*** correspond to the interstices. These points are located in the sum curve, and the positions corresponding to these points are found in the fabric image. To locate the yarns, an inverse coordinate transform should be carried out for the pixels. According to Equations 3 and 4, we can restore the coordinates of pixels in the fabric image. Weft and warp segmentation results are shown in ***Figure 12*** (see page 49). From the figure, it can be seen that the segmentation results are similar to those for human vision, therefore proving the efficiency of the method proposed.

Results and discussion

Yarn segmentation results for different fabrics

To investigate the efficiency of the algorithm proposed in this study, a set of fabrics with different colours or different weave patterns are selected to validate the method. ***Table 1*** shows some of the results. In order to clearly show this, some parts of the fabric images are displayed here. From the table it can be seen that the algorithm can segment warp and weft yarns in fabrics with different colours or different weave patterns.

Detecting the fabric density automatically

If the warps and wefts are segmented successfully, the fabric density can be obtained by counting the number of yarns in a unit length. In the experiment, we measured the amount of yarns in an inch using an automatic counting method. We also measured the fabric density five times manually with a textile analysis magnifying glass and then averaged the measurement results as the final manual result. The densities of the eight fabrics shown in ***Figure 1*** and ***Table 1*** are used to compare the difference between the automatic and manual methods. ***Table 2*** shows the comparison results. $Error = |Dm - Da|/Dm \times 100\%$, where Dm represents the density measured manually, and Da - the density measured automatically.

From ***Table 2***, it can be seen that the density results measured automatically and manually are almost the same, with the maximum error of the warp density being 0.39% and the maximum error of the weft density - 0.38%. The manual measurement result can only reach a precision of 0.5 thread, whereas the automatic measurement result based on image analysis can reach a precision of one pixel. For the entire fabric, the result detected by the method proposed in this study is closer to the true value.

Conclusions

The Hough transform was used to detect the skew angles of warps and wefts, and then the coordinate of the pixels was transformed based on different fabric models. The local minimum points were eliminated by the filters in the projection curve, and the true minima that represent the interstices could be located. The yarns in a fabric can be segmented successfully by locating the positions of the interstices. The fabric density is measured by counting the yarns in a unit length. The experiment proves that the algorithm proposed in this study can be used to inspect the density of solid fabric automatically. From the results shown in ***Tables 1*** and ***2***, it can be seen that there is no clear difference between fabrics with different fabric patterns. In order to complete the whole detecting system, we still need to discuss density inspection methods for single-system-mélange colour fabric and double-system-mélange colour fabric, which will be discussed in further article.

Acknowledgments

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