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Article

Automatic Detection of the Layout of Color Yarns for Yarn-dyed Fabric via a FCM Algorithm

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Abstract In the process of analyzing the yarn-dyed fabric, two kinds of color information about color yarns should be detected: (1) the number of yarn colors; (2) the layout of the color yarns. The traditional detection methods are time-consuming and labor-intensive. An automatic method based on image analysis is proposed in this study. The image of yarn-dyed fabric captured with a flat scanner is analyzed by a fuzzy C-means clustering (FCM) algorithm. By the analysis of the image of the yarn-dyed fabric based with the FCM algorithm, we can conclude that the number of yarn colors can be obtained with cluster validity analysis, and the layout of color yarns can be inspected automatically with the help of Hough transform. Experiments on two actual fabrics show that the approach proposed in this study is effective for detecting the number of yarn colors and the layout of color yarns in the yarn-dyed fabric.

Key words yarn-dyed fabric, FCM algorithm, layout of color yarns, number of yarn colors, cluster validity, Hough transform

With the development of computer technology, many researchers have tried to recognize the woven fabric parameters by image analysis. Kang et al. [1], Lin [2] and Kuo et al. [3] inspected the pattern and density of woven fabric based on image processing techniques. Although image processing techniques for fabric are maturing, the focus is still mainly on the analysis of grayscale fabric images. However, in actual practice, the visual recognition for yarn-dyed fabrics is as important as white fabrics, especially in sample analysis. It is highly desirable to develop an automatic detection approach for yarn-dyed fabrics using color image processing techniques.

In the process of analyzing the yarn-dyed fabrics, two kinds of color information should be detected: (1) the number of yarn colors; (2) the layout of color yarns. It is impossible to detect the number of yarn colors and the layout of color yarns in yarn-dyed fabric with grayscale image processing techniques. Compared with most of the normal color images, the color in yarn-dyed fabric is scattered and uneven because of the layout of color yarns and dyeing, so it is hard to locate the yarns directly from the color in the yarn-dyed fabric. The first step for recognizing the number of yarn colors and the layout of color yarns of yarn-dyed fabric is to classify the colors in the yarn-dyed fabric image.

As yarn-dyed fabric has its own characteristics, satisfactory color classification results cannot be obtained easily with normal methods, such as threshold, gradient analysis. Kuo et al. [4] used a fuzzy C-means clustering (FCM) algorithm to analyze the color segmentation for printed fabrics

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in the RGB color space, and the colors were classified successfully with the unsupervised clustering method. Pan et al. [5] used an improved FCM algorithm to classify the colors in yarn-dyed fabric in the HSL color space, and satisfactory results were also obtained for some yarn-dyed fabrics. In a different study, we found that both RGB and HSL color spaces have their own faults for the color classification of yarn-dyed fabric. The colors in some yarn-dyed fabrics cannot be classified successfully in either of the two color spaces. In this study, we try to use the FCM algorithm in the Lab color space to analyze the color information in yarn-dyed fabric. By an analysis of the image of yarn-dyed fabric based on the FCM algorithm, we can conclude that the number of yarn colors can be obtained with cluster validity analysis, and the layout of color yarns can be inspected automatically with the help of Hough transform. Experiments on two actual fabrics show that the approach proposed in this study is more effective than traditional methods for detecting the number of yarn colors and the layout of color yarns in the yarn-dyed fabric.

Research Methods

CIE-Lab Color Model

The image is expressed or saved in a RGB color model in the computer. Compared with RGB color model, the Lab color model [6] approximates human vision and aspires to perceptual uniformity. As the fabric image cannot be converted directly from the RGB color model to the Lab color model, the image is first changed to an XYZ color model as follows:

1. $r = R/255$ (1)
2. if $(r > 0.04045)$ $r = \left(\dfrac{r + 0.055}{1.055}\right)^{2.4}$, else $r = \dfrac{r}{12.92}$

   To obtain g and b, G and B are processed in the same way:
3. $$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2106 & 0.7125 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \cdot \begin{bmatrix} r \\ g \\ b \end{bmatrix} \quad (2)$$

Next, the image can be converted into a Lab color model with the help of an XYZ color model:

1. if $(X > 0.008856)$ $x = X^{\frac{1}{3}}$,

   else $x = 7.787 \times X + \dfrac{16}{116}$.
3. Y, Z are processed as X in step 1, and y, z can be obtained.
3. $$\begin{cases} L = 116 \times y - 16 \\ a = 500 \times (x - y) \\ b = 200 \times (y - z) \end{cases} \quad (3)$$

After the conversion, L, a, b are all in the interval [–128, 128], so clustering method can be used to classify the colors in the image of yarn-dyed fabric directly.

Fuzzy C-Means Clustering Method

In image segmentation and pattern recognition, clustering [7] is one of the most important processes. Among the clustering methods, FCM is the most famous. FCM is an unsupervised clustering method and it attempts to minimize the objection function by organizing the data into different clusters. The objective function is as follows:

$$J_m(U, V) = \sum_{j=1}^{n}\sum_{i=1}^{c} u_{ij}^{m} d_{ij}^{2} \quad (4)$$

where n is the data number; c is the cluster number; U is the membership degree matrix; V is the cluster center matrix; u_{ij} expresses the membership degree of the data point x_j belonging to the ith group and satisfies the following two conditions:

$$u_{ij} \in [0, 1], \quad i = 1, 2, \ldots, c \quad \text{and}$$

$$\sum_{i=1}^{c} u_{ij} = 1, j = 1, 2, \ldots, n$$

Here $m \in (1, +\infty)$, is a weighting exponent that influences the fuzziness of the clusters and controls the sharing degree between different cluster groups. The term $d_{ij} = \|x_j - v_i\|$, expresses the Euclidean distance between the ith cluster center v_i and the jth point x_j.

Bezdek [8] suggested that the FCM algorithm start with an initial guess for the cluster centers, which is intended to mark the mean location of each cluster. The initial guess for these cluster centers will most likely be incorrect. Therefore, in the experiment we chose to initialize the membership degree matrix instead. The FCM algorithm is implemented as follows:

1. Choose the cluster number c, the weighting exponent m and the terminative precision ε.
2. Initialize the membership degree matrix $U^{(0)}$ and set the iteration counter $t = 1$.
3. Update the cluster center matrix using the membership degree matrix:

$$v_i = \sum_{j=1}^{n} u_{ij}^{m} x_j \Big/ \sum_{j=1}^{n} u_{ij}^{m}, \quad i = 1, 2, \ldots, c \quad (5)$$

4. Update the membership degree matrix U, and set $t = t + 1$.

$$u_{ij} = \left[\sum_{k=1}^{c}\left(\frac{d_{ij}}{d_{kj}}\right)^{\frac{2}{m-1}}\right]^{-1} \tag{6}$$

If $d_{kj} = 0$, $u_{kj} = 1$, and $u_{ij} = 0$ $(i \neq k)$.

5. If $\left|U^{(t+1)} - U^{(t)}\right| \leq \varepsilon$, stop the iteration, otherwise go to step 3.

Cluster Validity Analysis

Cluster validity analysis is adopted to detect the number of yarn colors in the yarn-dyed fabric in this study. In the FCM method, the cluster number c is one of the most important parameters. With the same data, the classification results may be quite different as they adopt different c values. Cluster validity analysis is used to find the optimal cluster number. In the color classification for a yarn-dyed fabric image, the optimal cluster number may be equal to the number of yarn colors in the fabric. To validate this theory, the optimal cluster number is found by the specific cluster validity criterion (SC) introduced by Zahid et al. [9]:

$$SC = \frac{S}{\pi} - \frac{FS}{FC} \tag{7}$$

where

$$S = \frac{\sum_{i=1}^{c}\|v_j - \bar{x}\|}{c},$$

$$\bar{x} = \frac{1}{n}\sum_{j=1}^{n}x_j,$$

$$\pi = \sum_{i=1}^{c}\frac{\sum_{j=1}^{n}u_{ij}^{m}\|x_j - v_i\|}{\sum_{j=1}^{n}u_{ij}},$$

$$FS = \sum_{i=1}^{c-1}\sum_{r=1}^{c-i}\frac{\sum_{j=1}^{n}\min(u_{ij}, u_{kj})^2}{\sum_{j=1}^{n}\min(u_{ij}, u_{kj})}, \quad k = r+i,,$$

and

$$FC = \frac{\sum_{j=1}^{n}\left(\begin{matrix}\max_i u_{ij}\\ 1 \leq i \leq c\end{matrix}\right)^2}{\sum_{j=1}^{n}\left(\begin{matrix}\max_i u_{ij}\\ 1 \leq i \leq c\end{matrix}\right)}$$

The cluster number c corresponding to the maximum SC is considered as optimal, and it will be checked whether it is equal to the number of yarn colors in the yarn-dyed fabric.

Hough Transform

It is hard to locate the yarns directly because of skew yarns in the fabric, so the skew of warps and wefts should be detected in the experiment. Hough transform first proposed by Hough in 1962 [10] can detect the lines in the 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, 12], the interested line shown in Figure 1 can be expressed by

$$s = x\cos\theta + y\sin\theta \tag{8}$$

With Equation (8), the points in image space can be changed into parameter space by Hough transform. As shown in Figure 2, the (s, θ) parameter space can be divided into a number of small blocks. Each block indicates a straight line. Here H and W express the height and width of the image, respectively. To detect the lines in the image space, it just needs to search all of the interested pixels in the image and calculate all of the corresponding (s, θ) pairs. The straight lines in the image space can be found by searching the peaks in such a parameter space.

Hough transform can be carried out [13] with the following steps:

1. Define the increments of s and θ: Δs and $\Delta\theta$.
2. For each interested pixel, calculate the corresponding s value for each θ in parameter space using Equation (8).

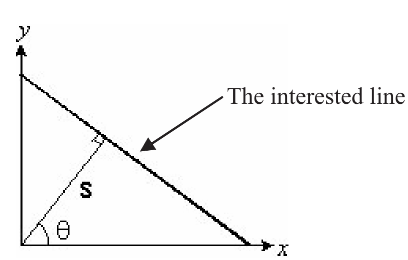


Figure 1 Theory of Hough transform.

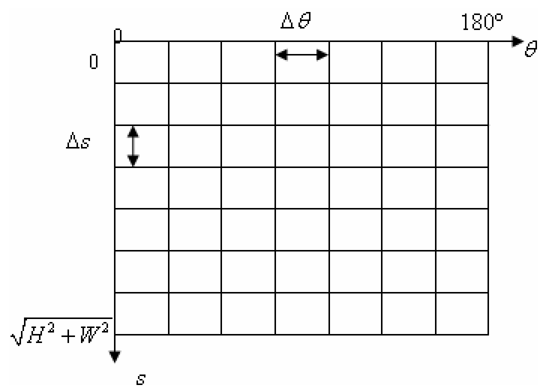


Figure 2 The (s, θ) parameter space.

3. Accumulate (s, θ) pairs for each block, find the line which is defined by the block with maximum value in a certain angle range.

Pre-processing for Hough Transform

The traditional method of Hough transform needs too much computing time. To reduce the calculation, some pre-processing should be performed for the yarn-dyed fabric image before detecting the skew of warps and wefts. As the edge of the yarns is parallel to the yarns, Hough transform is just applied to the edge pixels of the yarns in the experiment. The edge pixels of the yarns are detected with Laplacian algorithm [14]. The kernel of the Laplacian is as follows:

$$\nabla^2 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix} \qquad (9)$$

Experiment

A Microtek flat scanner was used to capture plain fabric images in RGB true color mode. For testing the devised approach, two fabrics are used. One sample fabric is composed of yarns with one of three different light colors, and the other consists of those of one of three different dark colors. The captured images of yarn-dyed fabrics consist of 768 × 768 pixels with the resolution 1200dpi. Microsoft Visual C++ is used as a software tool to develop the recognition system.

To illustrate the procedures of the developed system proposed in this study, a schematic diagram is given in Figure 3.

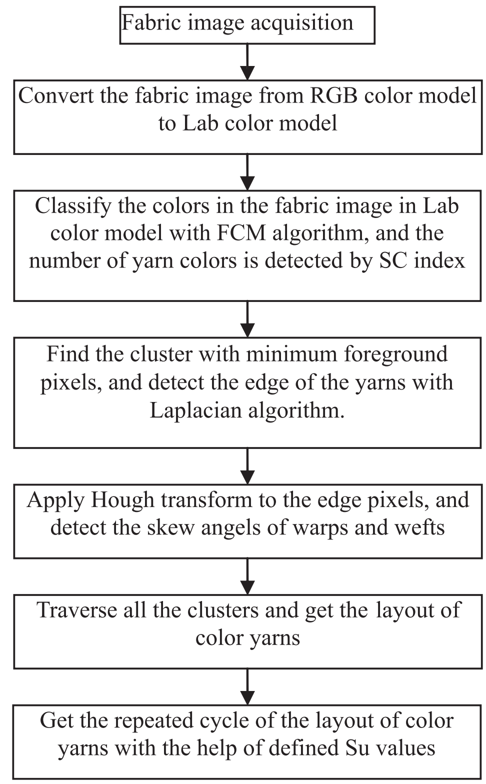


Figure 3 Schematic diagram of the algorithm.

During the process of image acquisition, the fabric is placed in position without skew, so the skew of the warps and wefts is no more than a certain angle range. In this study, skew of the yarns is considered as no more than 20°. The wefts are in the horizontal direction in the fabric image as shown in Figure 4(a). When detecting the skew of wefts, the skew angle is considered to fall in the range of [0°, 10°] or [170°, 180°]. The block with the maximum value in the (s, θ) parameter space within the angle range is located, and the corresponding angle is considered as the skew angle of wefts. When detecting the skew of warps, the angle range is set as [80°, 100°]. With the similar process, the skew angle of warps can be detected automatically.

The search for good color classification results can be carried out with the following steps:

1. Initial setting: $c = 2$, $c_{max} = 10$, where c is the cluster number and c_{max} is the maximum probability cluster number in the experiment.
2. Use the FCM algorithm (the weighting exponent $m = 2$ and the terminative precision $\varepsilon = 10^{-3}$) to computer the cluster center and membership degree matrix.

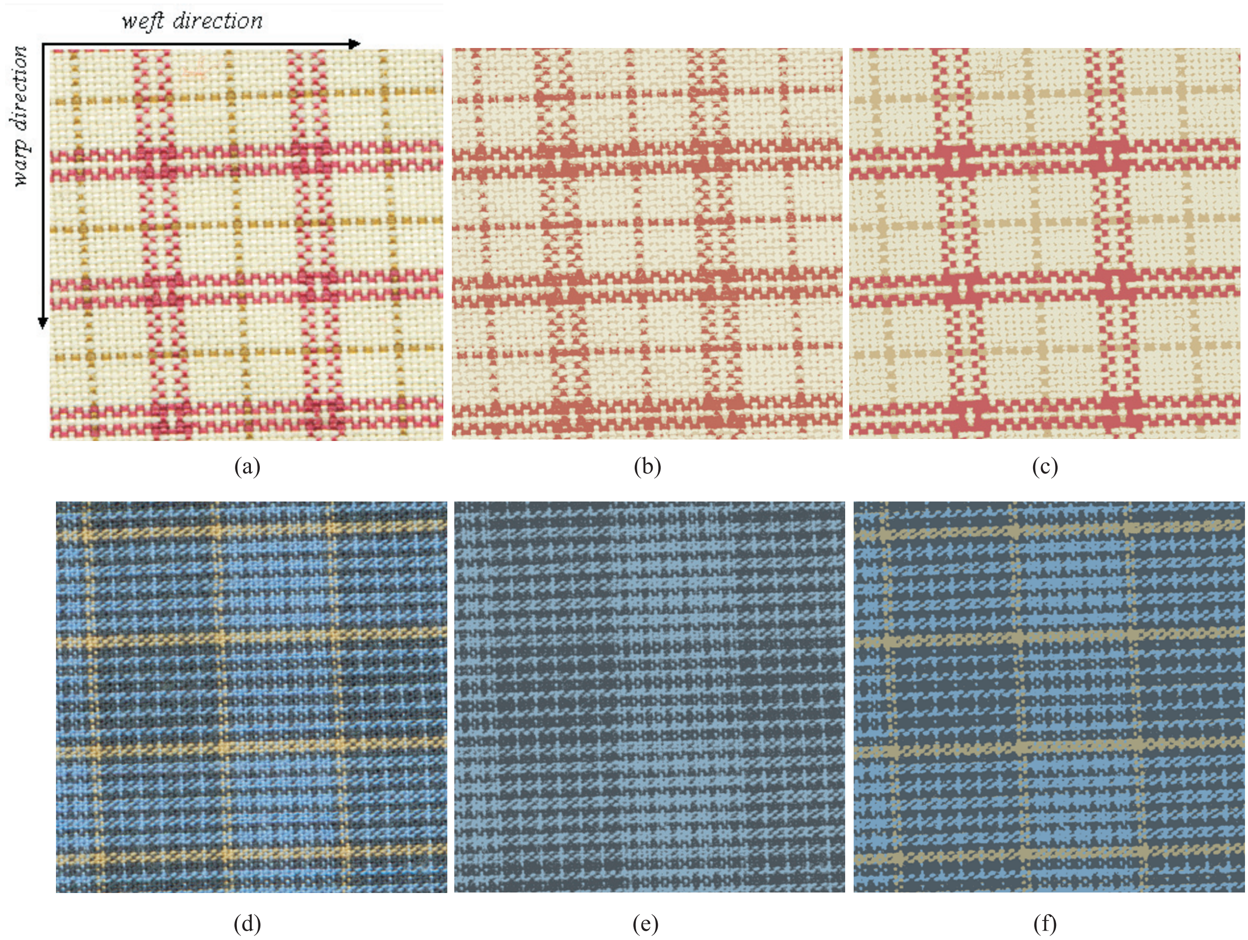


Figure 4 Classification results with FCM algorithm for fabric images: (a), (d) original fabric image; (b), (e) classification results in the RGB color model ($c = 3$); (c), (f) classification results in the Lab color model ($c = 3$).

3. Computer the cluster validity index *SC* and store the cluster center matrix in the memory.
4. If $c > c_{max}$, stop the iteration, otherwise set $c = c + 1$ and go to step 2.
5. Find the maximum *SC* index, use the corresponding the cluster number c and the cluster center matrix stored in the memory to classify the colors in the image of the yarn-dyed fabric.

Results and Discussion

Detection of the Number of Yarn Colors

The samples of plain fabrics used in this study are shown in Figure 4(a) and (d). All of the fabric images are laid out as in Figure 4(a) during the acquisition process. By using the FCM algorithm, the pixels in the image can be classified into different clusters. The results based on the Lab color model are shown in Figure 4(c) and (f). To show the advantages of Lab color model, the classification results in the RGB color model are also illustrated in Figure 4(b) and (e).

From Figure 4(b) and (e), it can be seen that both the light-color fabric (LCF) image and dark-color fabric (DCF) image are not segmented correctly in the RGB color model. This misclassification for the color pixels is probably because of the linear correlation between the three components (red, green, and blue) of the RGB color model. Although the cluster number is set as three, the brown yarns are misclassified into the red yarn cluster in the LCF image and the yellow yarns are misclassified into the light blue cluster in the DCF image. The third cluster in both LCF and DCF expresses the boundary pixels in the fabric image, which

Table 1 *SC* indices for the different fabrics.

c	2	3	4	5	6	7	8	9	10
LCF	–0.255	**–0.224**	–0.262	–0.248	–0.336	–0.258	–0.239	–0.237	–0.228
DCF	–0.366	**–0.198**	–0.255	–0.332	–0.487	–0.366	–0.354	–0.342	–0.269

are useless in our research. However, in the Lab color model the colors in both LCF and DCF are classified successfully, and the color information is similar to the original fabric images.

To find the optimal cluster number or the number of yarn colors in the yarn-dyed fabric, the cluster validity index *SC* is computed in the experiment. In the general case, the fabric has no more than 10 color yarns, so we set $c_{\max} = 10$ in the recognition system. The *SC* indices of DCF and LCF are shown in Table 1.

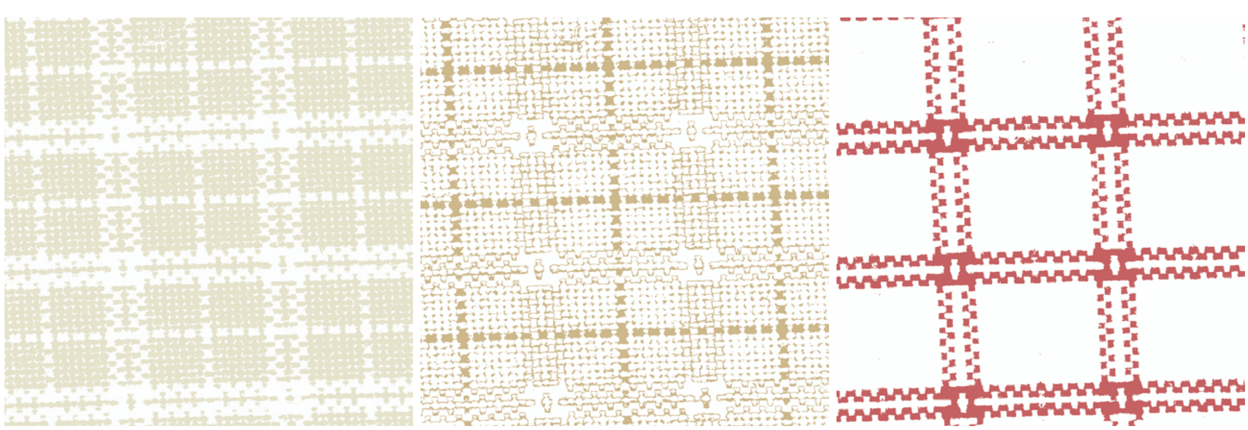
In the previous section, it was stated that the reference fabrics are composed of three different color yarns. From Table 1, it can be seen that the cluster number equals three when the *SC* indices of LCF and DCF reach the maximum. In the experiment, *SC* indices are computed for yarn-dyed fabrics composed of different numbers of yarn colors, and the results also show that the corresponding cluster number is equal to the number of yarn colors in the yarn-dyed fabric when *SC* index reaches the maximum. This fact proves that the number of yarn colors can be obtained by finding the cluster number when the *SC* index reaches the maximum.

Detection of the Layout of Color Yarns

To obtain the layout of the color yarns, the classification results are discussed in different clusters. Figure 5 shows the three clusters of the LCF. The background of the images is set to be white. It can be seen that there are some noise points in clusters 1 and 2. These noise points are eliminated by morphological closing [14] before recognizing the layout of color yarns. The images should be converted from RGB color mode into grayscale mode in order to use the close processing.

In Figure 6 the results after close processing show that most of the noise points in different clusters are eliminated. Although there are still some isolated noise points in cluster 2, it will not affect the recognition results of the layout of color yarns.

Different color yarns should be located in different clusters before detecting the layout of color yarns. In an ideal fabric, the warp yarns lie in the vertical direction while the weft yarns lie in the horizontal direction. As shown in Figure 6, the yarns are laid in neither the right horizontal nor right vertical direction. So the skew of warps and wefts is first detected by a Hough transform. The cluster with the fewest foreground pixels is chosen to find the skew angles. The edge of the yarns is detected with a Laplacian algorithm to reduce the computation, and Figure 7 shows the edge of yarns in cluster 2. Hough transform ($\Delta s = 1$ pixel, $\Delta\theta = 0.5°$) is then applied to the white pixels in Figure 7. The angle of the block located with the maximum value in the angle range of [0°, 10°] and [170°, 180°] in (s, θ) parameter space is considered as the skew angle of wefts. The



(a) (b) (c)

Figure 5 Classification results of the LCF by the FCM algorithm: cluster 1 ; (b) cluster 2 ; (c) cluster 3 .

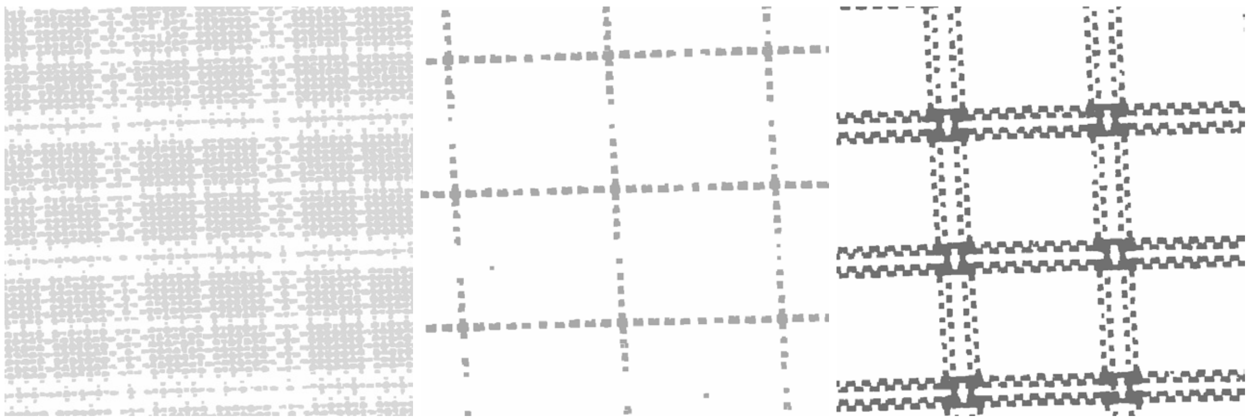


Figure 6 Classification results after close processing for the LCF: (a) cluster 1; (b) cluster 2; (c) cluster 3.

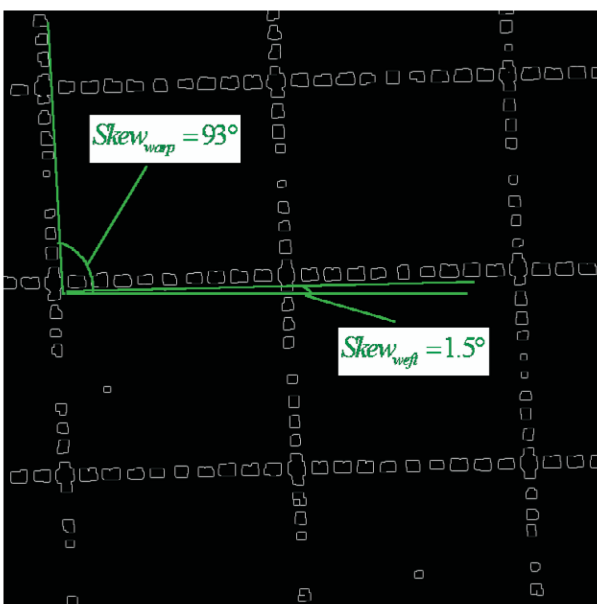


Figure 7 Edge of yarns in cluster 2 for the LCF.

skew angle of warps can be detected within the angle range [80°, 100°] with a similar process. The skew of the wefts in the LCF is 1.5° while that of the warps is 93°. The two skew angles are illustrated in Figure 7.

After the skew of yarns is detected, the image is traversed along the warp-skew direction and the weft-skew direction in different clusters to find the yarns and determine the color information of the yarns. In the experiment, the sub-images obtained by FCM, as shown in Figure 6, are detected at the same time. When a yarn is located, the foreground pixels of different sub-images in the yarn are accumulated. The foreground color of the sub-image in Figure 5 corresponding to the maximum value in the accumulated results is considered as the color of this yarn. The yarns in the marginal regions of the fabric image are eliminated. The layout of color yarns will be obtained by synthesizing the results in all of the clusters. The yarns in different clusters are expressed with symbols 'A', 'B', and so on. The layout of warp and weft yarns of LCF is shown as follows:

- Warp: 2A1B7A2C1A2C7A1B7A2C1A2C7A1B4A (from left to right).
- Weft: 2C1A2C7A1B7A2C1A2C7A1B7A2C1A2C7A1B5A (from bottom to top).

A novel algorithm is adopted to obtain the repeated cycle of the layout of warp and weft. Two assumptions are related first before explaining the algorithm.

Assumption 1: *There is no error in the recognized result of the layout of color yarns*.

Assumption 2: *There is at least one complete cycle in the fabric image*.

If the recognized result satisfies the two assumptions, the algorithm for detecting the repeated cycle can be carried out with the following steps:

1. Assign the recognized results (the color of each yarn) to a vector $V(1:N)$, where N is the number of

the warp yarn (weft yarn) in the image of the tested fabric. Initiate the iteration counter $t = 2$, the summation value $Su = 0$.

2. Create a new vector $W(1 : N - t + 1) = V(t : N)$ with the variable of iteration counter t. The new vector records the information from the tth yarn to the Nth yarn in the recognized result.
3. Calculate the summation value Su for $i = 1, 2, \ldots, N - t + 1$ according to the following conditions:

$$Su = Su, \quad \text{if} \quad V(i) = W(i)$$

$$Su = Su + 1, \quad \text{if} \quad V(i) \neq W(i)$$

4. Check the value of Su calculated at the iteration counter of t. If it is zero, the repeat cycle T can be obtained as the value $t - 1$ and stop the iteration. Otherwise set the value of $Su = 0$, and increase the value of iteration counter $t = t + 1$, clear all of the contents of vector W and then go to step 2.

With these steps, it can be seen that the color yarn information repeats from the tth yarn when $Su = 0$. The yarns before the tth yarn form a repeated cycle. Therefore, the repeated cycle of the layout of color yarns T equals $t - 1$ when $Su = 0$. The repeated cycles of the layout of warp and weft yarns can be calculated automatically with this novel algorithm. The Su values of LCF are shown in Figure 8. From the figure, it can be seen that $(t - 1) = 20$, $Su = 0$, from which we obtain a conclusion that the warp and weft cycles are both equal to 20. Therefore, the recognition system outputs the layout of warp and weft yarns as follows:

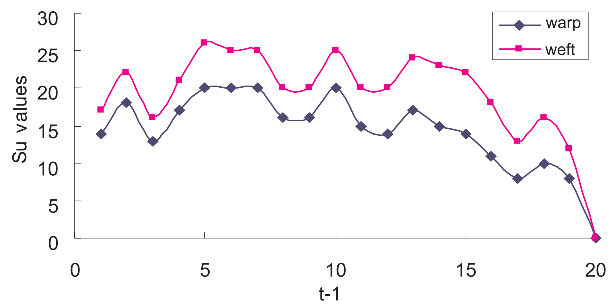
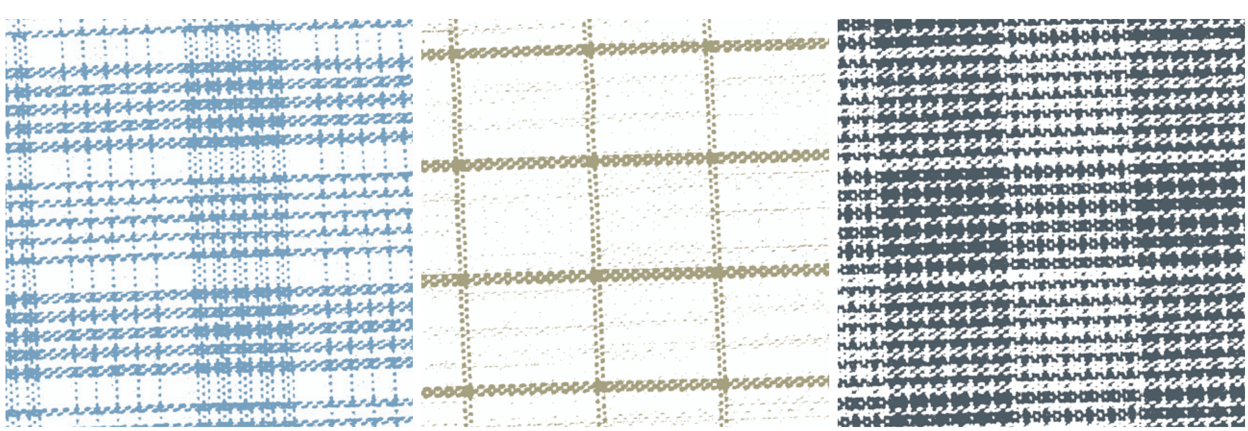


Figure 8 *Su* values of the layout of warp and weft yarns in the LCF.

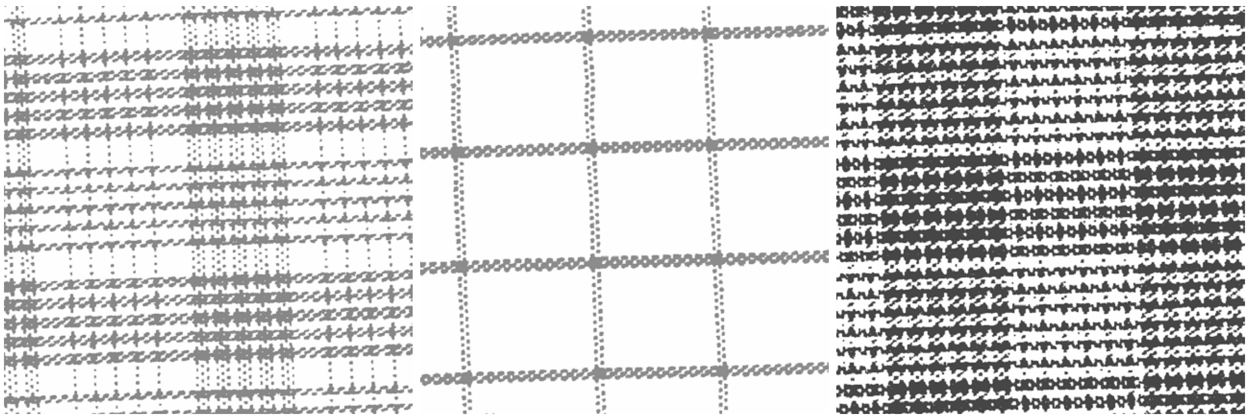
- Warp: 2A1B7A2C1A2C5A (from left to right): A ; B ; C .
- Weft: 2C1A2C7A1B7A (from bottom to up): A ; B ; C .

The layout of color yarns of the LCF has already been recognized. These steps are also applied to the DCF to validate the method proposed. Figure 9 shows the different clusters of the DCF obtained from the FCM algorithm. These images are then processed by close processing as shown in Figure 10. A Laplacian algorithm is used to detect the yarn edge of cluster 2 with the fewest foreground pixels, and then Hough transform ($\Delta s = 1$ pixel, $\Delta\theta = 0.5°$) is applied to the edge pixels. The skew of yarns are automatically inspected. The skew angle of the wefts in DCF is 2° while that of the warps is 92°.



(a) (b) (c)

Figure 9 Classification results of the DCF by the FCM algorithm: (a) cluster 1 ; (b) cluster 2 ; (c) cluster 3 .



(a) (b) (c)

Figure 10 Classification results after close processing for the DCF: (a) cluster 1; (b) cluster 2; (c) cluster 3.

As the skew of yarns is detected, the layout of color yarns of the DCF can be obtained in a similar manner as with the LCF. The detected results are as follows:

- Warp: 1C3A1C2B3C1A3C1A3C1A3C1A3C1A3C2B1C3A1C3A1C3A1C3A1C3A1C2B3C1A3C1A3C1A3C1A3C (from left to right)
- Weft: 2A3C3B2C3A2C3A2C3A2C3A2C3A2C3B3C2A3C2A3C2A3C2A3C3B2C3A2C3A2C3A2C3A2C1A (from bottom to up)

Su values are also employed to find the repeated cycle of the layout of warp and weft yarns for DCF. From Figure 11, it can be seen that $(t-1) = 48$, $Su = 0$ for the layout of warp yarns, $(t-1) = 56$, $Su = 0$ for the layout of weft yarns, which means that the repeated cycle of the layout of warp yarns is 48 while that of the layout of weft yarns is 56. Therefore, the recognition system outputs the layout of warp and weft yarns of DCF as follows:

- Warp: 1C3A1C2B3C1A3C1A3C1A3C1A3C1A3C2B1C3A1C3A1C3A1C3A (from left to right): A ; B ; C .
- Weft: 2A3C3B2C3A2C3A2C3A2C3A2C3A2C3B3C2A3C2A3C2A3C (from bottom to up): A ; B ; C .

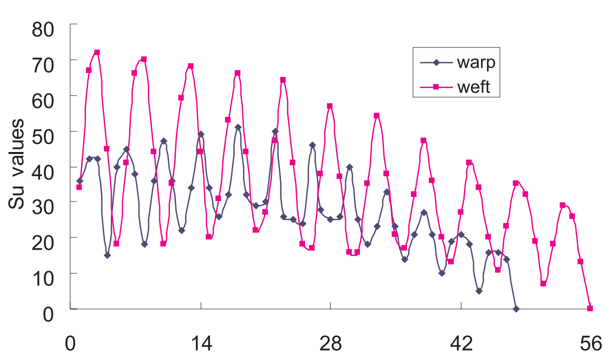


Figure 11 *Su* values of the layout of the warp and weft yarns in the DCF.

Conclusions

In this paper the color yarn number and the layout of color yarns of a LCF and a DCF have been recognized automatically, and the correct results prove that the method proposed in this study can detect the number of yarn colors and the layout of color yarns successfully.

We have proposed several methods to constitute the recognition system for the number of yarn colors and the layout of color yarns. The fabric image captured by a flat scanner is converted from a RGB color model into a Lab color model. The FCM algorithm is used to classify the pixels in the fabric image with a Lab color model. The number of yarn colors can be obtained by choosing the optimal cluster number with cluster validity analysis. Morphological close processing is adopted to remove the noise points in different clusters. The edge of the yarns in the cluster with the minimum foreground pixels is detected by a Laplacian algorithm, and Hough transform is applied to white pixels in the edge detection results to inspect the skew angles of warp and weft yarns. The layout of color yarns can be obtained by traversing all of the clusters. With the help of *Su* values defined in this study, the repeated cycles can be calculated automatically, and finally the recognition system can output the layout of warp and weft yarns correctly. The experiment on two plain fabrics, a LCF and a DCF, proves the efficiency of the proposed approach. As the color yarn information in twill fabrics is similar to plain fabrics, the recognition system can also be used for the detection of the number of yarn colors and the layout of color yarns for twill fabrics. The yarns in the satin fabrics are close and overlap, so the algorithm proposed in this paper is not good for recognizing the layout of color yarns of satin fabrics, and more detailed research for stain fabrics is needed in the future.

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