Study on fabric density identification based on binary feature matrix

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In order to correctly identify the fabric density, a new algorithm based on binary feature matrix is proposed in this paper. A best threshold plane is determined by the gray level of fabric image, the 3D gray image of fabric is segmented according to the best threshold plane and a gray image of feature cluster is obtained. Then the feature cluster is normalized to transform the fabric image into a binary feature matrix only with threshold value and feature value. Finally, equations for density computation of fabric with binary feature matrix are given. Experimental results show that the proposed algorithm possesses features of accurate computation and fast speed, which can effectively identify the fabric density and provide a new idea for density recognition.
Key words: *binary feature matrix, fabric, density, identification*

1. Introduction

The research of automatic identification for fabric density is an important task in textile field, which can improve the speed and accuracy of fabric density recognition. Scholars have done much exploration, but no perfect theory on this subject is available at present. Many existing methods of fabric density detection can be divided into two categories: spatial domain and frequency domain. Spatial domain approach involves digital image analysis, autocorrelation method, fuzzy clustering, and neural network. Digital image analysis was presented to recognize the fabric density [1]. The fabric image was converted in the horizontal or vertical direction by the gray value, the interlace position of weft and warp yarns was given by the geometry ratio analysis. In [2] autocorrelation method was applied to obtain the weave matrix and fabric density. The yarn with brightness analysis of yarn interstices was determined and the weft and warp weave points with the rising length ratio of weft and warp weave points was given. Fuzzy clustering has been applied to density detection in [3]. The membership degree of fabric image gray was calculated according to the closeness degree, the clustering of yarn and interstices was formed. Researchers used backward-propagation neural network method to construct the neurons and the neural network model with the image gray, and calculated various parameters by vector multiplication to extract the fabric density [4]. Recently, a number of new algorithms appear. The variation between the grays was obtained by the position computation between fabric image grays and gray difference to extract fabric density [5]. The fabric density was recognized according to color gradient construction with gradient method [6]. In addition, a number of researches of image characteristic, such as automatic capture of microscopic fiber [7], extraction method of defect characteristic [8] and intelligent method of evaluating the regularity of weft-knitted fabrics [9] also have an important reference meaning for fabric density.

Frequency domain is a method that the fabric image is transformed into various spectrums, the spectrum characteristic values are extracted to obtain each characteristic value of fabric, and the fabric density is analyzed automatically. Existing methods mainly includes Fourier transform, Gabor transform and wavelet transform.

Fourier transform was studied in [10-12]. The fabric image was transformed and the characteristic was analyzed to obtain the density feature of fabric. There are very few applications of Gabor transform in fabric density analysis. It mainly applied to the image transformation of fabric defect [13]. There was much information about fabric feature extraction with wavelet algorithm. Aruvazhagan [14], He [15] and Shen et al. [16] studied the algorithm and accomplished the fabric parameters analysis.

The above algorithms have their advantages, but still have two common problems. One is the accuracy of fabric feature found still needs to improve. The other is the computation method needs to simplify.

To solve these problems, this paper proposes a new algorithm of fabric density identification based on binary feature matrix. A 3D gray model of fabric image is constructed and a suiTab. threshold plane is selected. The gray 3D model is segmented to obtain feature cluster on the threshold plane, and the feature clusters is made the normalization. Finally, a binary feature matrix only including the threshold plane and feature cluster value is established to accomplish the density recognition of fabric.

2. Algorithm model

2.1. General idea

The key problem of texture extraction is to extract the feature point of weave. By observing the fabric image with pure color (Fig.1), it can be seen that feature points representing fabric weave appear on surface of the fabric with higher gray value, and the gray values of each feature point are in a range.

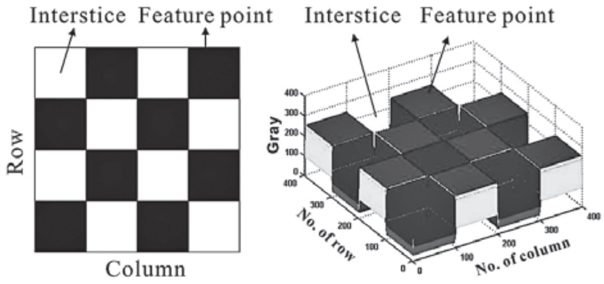

Fig.1 Position of feature point of idea weave in gray image

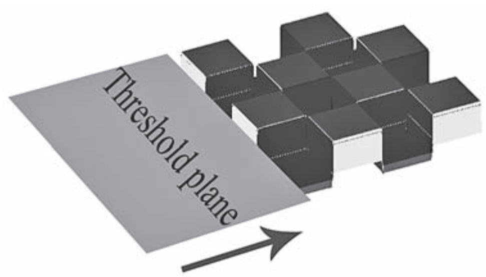

Fig.2 Division schematic diagram of feature cluster

Therefore, we try to determine a suiTab. height to segment the 3D gray image with a division plane as depicted in Fig.2. The pixel points that can denote fabric feature are separated from other points, and then the pixel points are made further processing to form feature points. We call the gray value of division height as threshold value, the division plane as threshold plane.

From Fig. 2, it can be imagined that the feature cluster can be segmented by the threshold plane as long as the division height is suiTab.. A new 3D gray image, which bottom is a threshold plane and many feature clusters are on the plane, is obtained. The gray value of other pixel points is same to that of the threshold plane except the feature clusters. It is easy to isolate the threshold plane and judge the feature cluster. These feature clusters can be transformed into feature values denoting fabric weave texture to establish a texture feature matrix.

However, the 3D gray images of fabric are not regular like that in Fig.1 and Fig.2 due to yarn bending and fabric luster. The feature cluster does not show a plane or point distribution but an irregular cluster distribution. Even so, as a whole, it is noticed that the feature clusters correspond to the feature points in the gray image as illustrated in Fig.3.

By observing Fig.3 in whole, some irregular feature clusters correspond to feature points of fabric. But the gray of each pixel point of feature cluster has no variation to follow. Therefore, a problem is how to transform these feature clusters with no regularity into that with regularity as illustrated in Fig.1 and 2. To solve this problem, the normalization method is introduced.

2.2. Detail model

2.2.1. Construction of gray matrix of fabric image

Suppose that the fabric image after image preprocessing is made of pixel points with the number of $N \times M$, the vertex O at the bottom of left corner of the image is origin, the horizontal direction is x axis, the vertical direction is y axis, the gray value of each pixel is z axis, a 3D space coordinates is constructed. Where, the values of x axis and y axis are natural numbers, the value range of z axis is [0,255].

Let the coordinate of any pixel points is x, y, the gray value is denoted by g

(x, y), then the gray matrix A_g of fabric image can be established as:

$$A_g = \begin{bmatrix} g(1,1) & g(1,2) & \dots & g(1,M) \\ g(2,1) & g(2,2) & \dots & g(2,M) \\ \dots & \dots & \dots & \dots \\ g(N,1) & g(N,2) & \dots & g(N,M) \end{bmatrix} \quad (1)$$

The 3D gray image is drawn by matrix A_g as shown in Fig. 3. It can be seen that the 3D gray image is clearly denoted by gray value.

2.2.2. Threshold plane selection

Selecting the threshold plane is the key in this study. If the threshold value is too large, the feature cluster can be omitted. Conversely, feature cluster cannot be segmented correctly.

Under an ideal state, the feature point will be segmented successfully when the threshold value is any value between the maximum value and minimum value of image gray as depicted in Fig.2. For real fabric image, the maximum and minimum values of gray are a value range, such as the 'feature cluster' in Fig.3. The gray values of pixel point in the region are not same, they are in a range. However, there are some independent pixel points in image, such as the pixel points of 'gray variation increase' in Fig.4. The gray value may increases (or decreases) and exceeds the value range of 'feature cluster'. It will be error if the threshold value is determined by the maximum and minimum values of all pixel points. The reason is that the maximum gray and minimum gray generated by variation point only are the gray value of individual pixel point, which doesn't accurately reflect the true feature of image.

Therefore, the adverse effects produced by gray variation must be eliminated before the threshold value is determined. To solve this problem, the number of the pixel points with the gray value should be taken into consideration when the gray value is studied. The maximum and minimum gray values generated by a few pixel points are judged as the variation gray value. The variation gray values are not considered when the threshold value is determined.

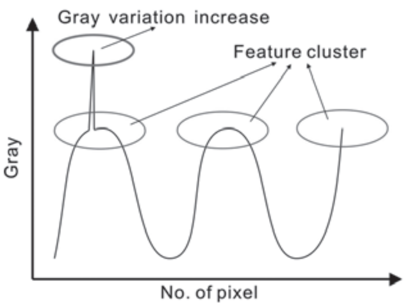

Fig.4 Variation of gray

For this reason, we introduce a gray level analysis method. Firstly, all gray values of fabric image are captured; the values are arranged with the order of gray value, and a gray level of image is formed. And then, the number of the corresponding pixel points in each gray level is calculated to establish a data structure which can describe the number of pixel points of each gray level. Let *T* denotes the number of pixel point of each gray level, the number of pixel points of each gray level is represented by *T(x)*, *x* is the gray level, and its value range is $[g_{MIN}, g_{MAX}]$, g_{MIN} and g_{MAX} represent the minimum and maximum values of image gray, respectively. The data structure can be described by the waveform of gray level as illustrated in Fig. 5. The first wave peak from left to right in the gray waveform is the true minimum x_l in the low gray range. The first wave peak from right to left is the true maximum value x_h in the high gray range.

When the threshold value is chosen, the pixel point that gray value is smaller than the value of x_l and larger than the value of x_h is judged as a variation point and is not taken into consideration.

The wave peak can be determined by the principle as follows: suppose the abscissa of any point of gray waveform in Fig. 5 is *x*, and that of the left point and right point are x_1 and x_2. If the three points meet the condition as

$$T(x) - T(x_1) > 0 \quad \text{i} \quad T(x) - T(x_2) > 0 \quad (2)$$

Then the wave peak at the position *x* is the local wave peak.

The true maximum gray value and true minimum gray value are determined according to the above analysis, and the threshold value is obtained using averaging method.

Let the value of threshold plane is G_a, it can be calculated as:

$$G_a = \frac{\sum_{i=x_l}^{x_h} iT(i)}{\sum_{j=x_l}^{x_h} T(j)} \quad (3)$$

2.2.3. Normalization of feature cluster

Several feature clusters denoting weave feature is obtained after the fabric image is segmented by threshold plane. Thus the feature cluster is determined as long as the boundary of feature cluster is judged by value-G_a. As shown in Fig.6, let the size of analysis region is $\Delta x \times \Delta y$, there are random pixel pointsin $p(x_1, y_1)$, $p(x_2, y_2)$ $p(x_c, y_c)$ the region. If

$$\{g(x_1, y_1), g(x_2, y_2), \dots, g(x_c, y_c)\} > G_a \quad (4)$$

Then $p(x_1, y_1)$, $p(x_2, y_2)$ $p(x_c, y_c)$ are the point sets of feature cluster. The pixel point, which satisfies the condition of feature cluster and is adjacent each other, is classified to the corresponding feature cluster using the connection method in computer ima-

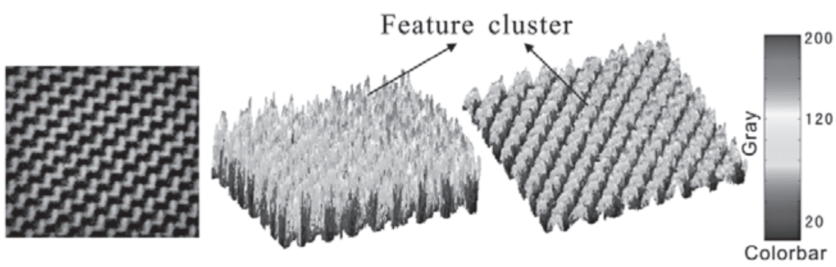

Fig.3 Schematic diagram of feature cluster of fabric

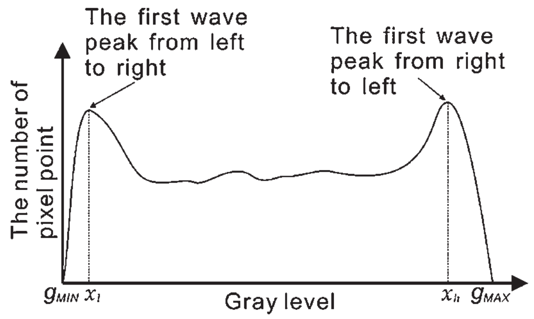

Fig.5 Waveform of gray level

ge processing [17]. Suppose the classification result is cluster S, there are m_k pixel points in the k cluster. Every feature cluster can be normalized as:

$$F_k = \frac{\sum_{i=1}^{m_k} g(x_i, y_i)}{m_k} \tag{5}$$

Where, F_k is the normalization value of the k cluster, $g(x_i, y_i)$ denotes the gray value of any point $p(x_i, y_i)$ in the k cluster. In order to construct a feature matrix, each feature cluster has the same gray value; the mean F_{AVE} of all feature clusters is calculated as:

$$F_{AVE} = \frac{\sum_{i=1}^{S} F_i}{S} \tag{6}$$

2.2.4. Establishment of binary feature matrix

A binary feature matrix F_T can be established after the feature cluster is normalized. The element value of this matrix only includes two values: the gray value F_{AVE} on feature cluster position and the threshold value G_a in the feature cluster interstices. The binary feature matrix F_T is expressed as:

$$F_T = \begin{bmatrix} F_{AVE} & G_a & \cdots & F_{AVE} \\ G_a & F_{AVE} & \cdots & G_a \\ \cdots & \cdots & \cdots & \cdots \\ F_{AVE} & G_a & \cdots & F_{AVE} \end{bmatrix}_{N_F \times M_F} \tag{7}$$

Where, $N_F \times M_F$ is the row and column of the binary feature matrix, F_{AVE} and G_a are random positions, which can be obtained by Equations (1)-(6).

2.2.5. Density identification

The fabric density can be easily calculated by the binary matrix F_T. Let the warp density of fabric is D_H (ends/10 cm), the weft density of fabric is D_V (ends/10 cm), the number of feature clusters in the i row of the binary matrix is P_i, the number of feature clusters in the j column is P_j, the sizes of image in the horizontal direction and vertical direction are L_H (cm) and L_V (cm). For the basic weave of fabric, the fabric density can be calculated as:

$$D_H = \frac{P_i}{L_H} \times 10 \tag{8}$$

$$D_V = \frac{P_j}{L_V} \times 10 \tag{9}$$

For complicated weave of fabric, the feature clusters of each row and each column in the binary matrix refer to the weave points of fabric. The fabric density can be calculated by autocorrelation method in [2].

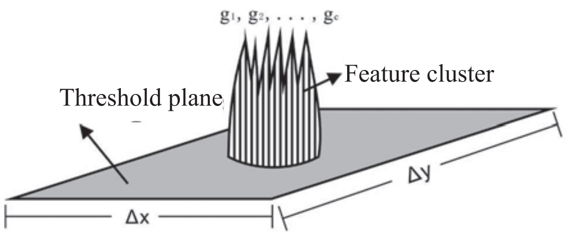

Fig.6 Feature cluster normalization

3. Results

3.1. Experimental method

To validate the proposed algorithm, the MATLAB 7.0 is used to compile the computer program. We select 60 kinds of fabrics with different density as samples. The weaves of sample are plain, twill, and satin, respectively. The size of sample is 10 x 10 cm. The sample images are captured under good nature light by a Canon EOS550D camera. The analysis region is any region in sample image with 72 ppi resolution. The 3D gray image, feature cluster image and the binary feature matrix of samples are output by computer. The density can be recognized by observing the waveform of the binary feature matrix.

3.2. Example results

The results of three samples illustrate Fig.7-9.

Fig.10 shows the waveform of sample 1 illustrated in Fig.7 in the row direction of the binary feature matrix.

3.3. Results of density identification

We analyze the binary feature matrixes of 60 prepared samples according to Equation (8) and Equation (9) to recognize the weft density and warp density. At the same time, we identify the weft density and warp density of the samples using the density identification equipment (YG871). The computer recognition results are compared with the manual inspection results to verify the accuracy of the binary feature matrix.

A relative error is introduced to evaluate the error between the computer recognition results and the manual inspection results. Suppose the recognition result by the binary feature image is D_C, the manual inspection

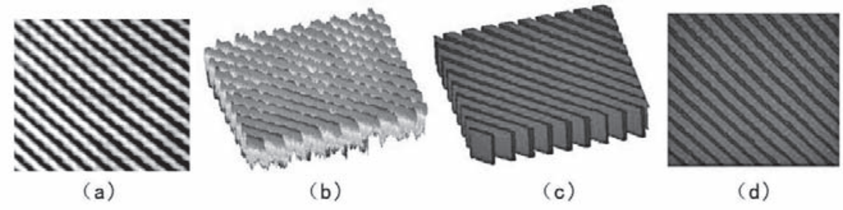

Fig.7 Original image (a), 3D gray image (b), feature cluster image (c) and binary feature matrix image of sample 1 (d)

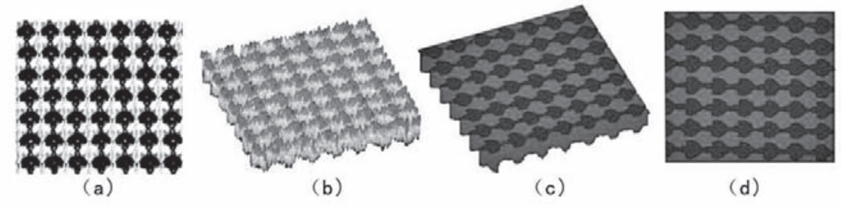

Fig.8 Original image (a), 3D gray image (b), feature cluster image (c) and binary feature matrix image of sample 2 (d)

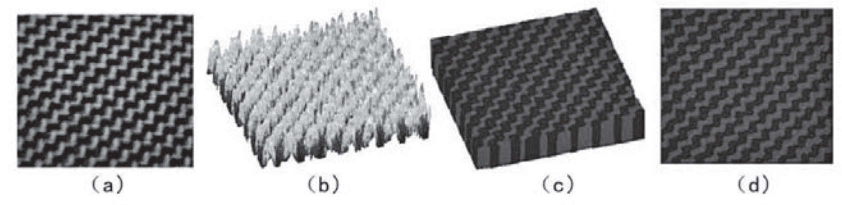

Fig.9 Original image (a), 3D gray image (b), feature cluster image (c) and binary feature matrix image of sample 3 (d)

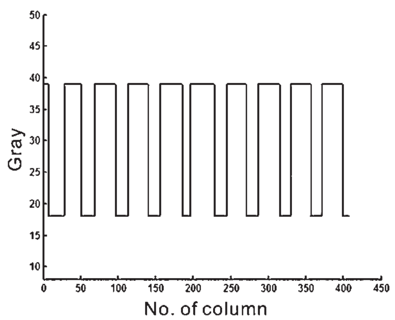

Fig.10 Waveform of sample 1 illustrated in Figure 7 in the row direction of the binary feature matrix

result is D_m. The relative error λ can be written as:

$$\lambda = \frac{|D_c - D_m|}{D_m} \times 100\% \qquad (10)$$

We calculate the values of λ by the recognition results of the weft density and warp density of each sample, divide the values of λ into 4 classifications: λ=10%, 10%≥ λ>5% and 5%≥ λ>0%**.** We count the number of values of λ that comply with above four classifications. Suppose the total number of identifications of the weft density and the warp density be W, S_i denotes the number of the values of λ that comply with the *i* th classification, R_i is the proportion of the value of S_i to the value of W. Therefore, R_i can be calculated as:

$$R_i = \frac{S_i}{W} \times 100\% \qquad (11)$$

The number of identifications of weft density or warp density of each samples is 1, so the value of W is 120 .The relative error λ results of 60 samples are listed in Tab.1.

According to Tab.1, it is observed that the recognition results by the binary feature matrix are accurate. The consistent rate between the computer recognition and manual identification reaches 92.5 %. The rate that the relative error is less than 5 % reaches 97.5 %, and the rate that the relative error is less than 10 % reaches 99.2 %, respectively. Therefore, it is concluded that the density recognition by the binary feature image has a good result.

4. Further discuss

4.1. Advantage of proposed algorithm

The purpose of the binary feature matrix establishment in this paper is to recognize the fabric density rapidly. The complicated image of fabric is transformed into a simple matrix expressed by two gray value using threshold plane, so that the inner feature of image is described effectively to provide the data basis for density recognition.

By observing Fig.7-9, the texture is extracted successfully and a binary feature matrix denoted only with two mean values of feature cluster F_{AVE} and threshold value G_a is formed after the image is processed by the proposed algorithm. All this provide convenience for further analysis of density. Fig.10 has proved that the waveform was pulse wave; the density feature of fabric was showed obviously. Therefore, the fabric density can be calculated by Equation (8) and Equation (9).

The proposed method for the plain weave fabric, the twill weave fabric and the satin weave fabric possesses good recognition effect according to the experimental results from Tab.1. Although we have not verified the recognition for other type weaves fabric, we find that the feature points of fabric can be capture by proposed method as long as the peaks and the troughs of the gray waveform of fabric are clear from the analysis of Fig.10 and Equation (10); the weft density and the warp density of fabric are obtained according to autocorrelation analysis of transversal gray waveform and longitudinal gray waveform. Therefore, the proposed algorithm possesses value for the density identification for most fabrics.

Tab.1 Density recognition error of 60 samples by the proposed algorithm

Warp	The number of samples in different error range			
	λ>10%	10%≥λ>5%	5%≥λ>0%	λ=0%
Warp density	1	1	3	55
Weft density	0	1	3	56
R_i (100%)	0.8	1.7	5	92.5

We mainly discuss the binary feature matrix model of fabric for density identification, subsequent processing for the model is no longer discussed here.

In fact, the binary matrix provides not only the data basis for fabric density computation but also the theoretical basis for fabric weaves and texture analysis. The essence of the binary matrix is to extract the feature information of fabric, remove some useless pixels, and express the fabric density with the simplest method. This method provides the convenience for the position judgment of wave peak and wave valley, for the distance computation between the wave peak and the wave valley, and for the computation of cycle number. Therefore, the proposed algorithm also has the reference value for other recognition of fabric parameters.

4.2. Quality requirement for fabric image

In order to establish the binary feature matrix, many points in the feature cluster are normalized to a value. The quality of image is important because each point in the feature cluster will be judged. The light of different regions of fabrics is different in experiments because of the surrounding light, making the photo processing difficult. The color and luster do not influence the image quality under the conditions of normal light, but the photo light is high under strong light, resulting in the gray wave is difficult to identify. Therefore, we must ensure the fabric is placed on the best plane, the light is even and soft, the brightness is moderate, and the digital camera focuses on the centre point of fabric. Even so, a number of small noises are produced. Therefore, the image must be preprocessed to eliminate the noise after the image is captured. In order to ensure the image clearer and more evenly, the image is denoised by median filter. The median filter is a very flexible method. Here we use a modified 2D bidirectional median filter method presented in our previous researches [18]. The detail function is given as:

$$G(i,j) = G_i \times \frac{L_w}{L_w + L_h} + G_j \times \frac{L_h}{L_w + L_h} \qquad (12)$$

Where, G_i represents output of lateral median filter, G_j is output of vertical median filter. L_w denotes the lateral window length, L_h refers to the vertical window length.

While G_i and G_j can be calculated as follows:

$$G_i = Med\{w_{i-v_w},\ldots,w_{i-1},w_i,w_{i+1},\ldots,w_{i+v_w}\} \qquad (13)$$

$$G_j = Med\{k_{j-v_k},\ldots,k_{j-1},k_j,k_{j+1},\ldots,k_{j+v_k}\} \qquad (14)$$

Where, v_w refers to the number of pixel value of lateral window, v_k indicates the number of pixel value of vertical window, *Med* denotes the median value of sequence.

4.3. Comparison analysis with other algorithm

The speed of the proposed algorithm is fast. From equations (1)-(9), it can be noticed that the processes of threshold value determination and binary feature matrix establishment are simple and the computation is low-level. Compared with Fourier, Wavelet and Fuzzy algorithm, the computation of the proposed algorithm is low, which can save computing time. In addition, the gray values of many pixel points in fabric are transformed into threshold values after the fabric image is segmented by threshold value. The gray distribution of image is simplified, which improve the progress and speed of further gray analysis.

The proposed algorithm has better recognition accuracy. We know that all points of image are made spectrum transform by the frequency domain method. Some useless points for image feature also made transform, which will influence the recognition accuracy. Also the point of image is processed with special domain, the recognition accuracy decreases by some useless pixel points. However, the binary feature matrix can effectively describe the texture characteristic of image using two gray values. It is easy to analyze the variation between the matrix factors. Thus the recognition result is more accurate and reliable. The extraction result by the binary feature matrix (Fig.7-8) and the recognition verification of density (Tab.1) show that the established binary feature matrix has the features of effectiveness and accuracy.

In addition, the proposed algorithm has abroad utilization, which can provide reference for recognition of fabric texture, texture evenness and weave points.

Therefore, compared with existing algorithms, the density recognition algorithm based on the binary feature matrix has the advantages as follows: fast recognition speed, high recognition accuracy and wide application.

5. Conclusion

The proposed algorithm can reasonably select the best threshold value for fabric image segment and obtain the feature cluster image on the threshold plane according to the 3D gray image of fabric.

The presented normalization function can effectively determine the region of the threshold plane and feature cluster to establish the binary feature matrix only with two values: feature cluster F_{AVE} and threshold value G_a.

The proposed algorithm can construct a data model of the binary feature matrix of fabric, which made convenience for parameters analysis of the alternative number of wave peak and valley, continuous length and interval distance, and can identify the fabric density rapidly and accurately.

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