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Skew Detection and Correction Method of Fabric Images Based on Hough Transform

Zhang ruilin, Hu yan, Fang zhijian, Zhang lei
Software Engineering Institute, Zhejiang Sci-Tech University
Hangzhou, P.R. China
e-mail: nancyhx2004@163.com

Abstract—**To solve the skew situation of scanned fabric image, a method based on Hough transform for skew detection and correction in fabric images was presented. By combining the characteristics of fabric images and the weft direction information extracted by Sobel operator, this method performed hierarchical Hough transform on the weft boundary to detect the skew angle of fabric image. Finally, a rotation algorithm based on the image linear storage structure was introduced, and the skew image was corrected rapidly. The skew detect algorithm has been experimented on various skew angles of fabric image and very promising results have been achieved given more than 99% accuracy. Experimental results show that the proposed method with high adaptability is more accurate and rapidly than traditional Hough transform.**

Keywords-skew correction angle detection Hough transform fabric image

I. INTRODUCTION

Recently, the development and widely use of digital image processing bring the traditional textile industry new vitality, which also change the backward situation of design and production of textiles in our country. However, various methods and techniques of relative research are established on the strict regulations of fabric images at present. Since the skew is inevitable during scanning fabric samples, the skew angle of fabric image has an obviously negative influence on automatic analysis and recognition of fabric image. Therefore, skew detection and correction of fabric images is an indispensable part of fabric image processing.

The core of skew detection is how to detect the skew angle. Image skew detection is often applied in document image processing research. There are a lot of methods for image skew detection, and one of them is Hough transform which is an effective method of line detection [1]. But unfortunately, comparing with document images, fabric images have more abundant color and texture information, and they don't have clear text region and line spacing region.

By considering the combination of the prior knowledge and general methods of document image, we utilize the own characteristics of fabric image to improve the performance of Hough transform. Although there's no straight lines in fabric images, ideal weft direction manifests as a group of horizontal line between which the width and space is relatively fixed. So the skew angle of fabric image can be detected by analysis on weft direction. A rapid skew detection algorithm combining Sobel operator and hierarchical Hough transform according to the characteristics of the fabric image is proposed to achieve higher accuracy and decrease interference caused by texture information. The algorithm selects a subregion of fabric image firstly, then utilizing Hough transform twice on the subregion. Hough transform is only applied on the weft boundary instead of all pixels, which can reduce the computational complexity and achieve the purpose of rapid detection. What's more, a rotation algorithm based on the image linear storage structure is also adopted to reduce the computational complexity and operation time of image skew correction.

II. FABRIC IMAGE PREPROCESSING

If fabric images are binarized directly, the precision of detection will be influenced by color, noise and etc. Therefore, some algorithms are used to pretreat fabric images before skew detection. Color image is transformed into gray image firstly and then the histograms are equalized over the gray image. Finally, we adopt median filter to remove the random noises which are caused by light and image acquisition device.

III. PRINCIPLE OF FABRIC IMAGE SKEW DETECTION

A. Hough transform

Hough transform is a commonly used detection method. It can detect and locate straight lines in image. It transforms binary images into Hough parametric space and detects targets by extreme point in the parameter space. A straight line in two-dimensional image can be expressed as [3]:

$$\rho = x\cos\theta + y\sin\theta \quad (1)$$

x, y are rectangular coordinate of pixels, ρ is the distance from origin to the straight line, $\theta (0 \le \theta < 2\pi)$ is the angle between normal of the straight line and x-axis. Thus, a straight line in the image is mapped into a point (ρ, θ) of the parameter space, and a point in the image corresponding to a sine curve of parameter space. Any two sine curves of parameter space which are in correspondence with two point (x_1,y_1), (x_2,y_2) of the image space are intersected at a point (ρ, θ). Therefore, all the sine curves corresponded with the points of the straight line which passed through point (x_1,y_1) and point (x_2,y_2) will intersect in this point (ρ, θ). Based on the above theories, the issue of straight line detection is converted to detect points in the parameter space, then find the local maximum of these points.

B. Weft boundary extraction

It will lead to high computing complexity, slow procedure computing speed and low adaptability if each pixel is calculated by Hough transform to detect the skew

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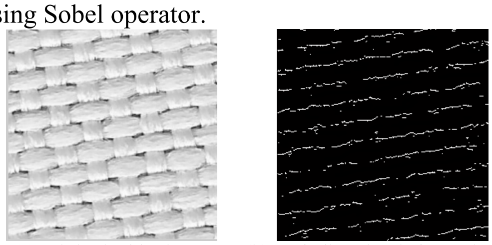
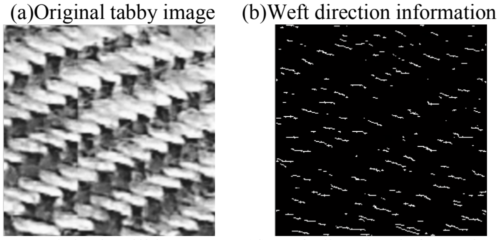
angle. Fabric images are a special kind of texture images. The warp and weft yarns are arranged closely and interlaced in specified organization. What's more, weft are woven in turn and arranged uniformly in actual fabric weaving process. Therefore, skew weft can characterize the deflection of fabric images. In accordance with the characteristic, we detect the skew angle of fabric images through the analysis of weft direction information.

We propose a robust approach for extracting the weft boundary based on Sobel operator. In this approach, the weft direction information is extracted from the fabric image by Sobel operator firstly, then hierarchical Hough transform is used to estimate the skew angle. Experiment results show that the approach not only reduces the computational complexity, but also improves the operating speed of the procedure. What's more, the peak of the accumulative matrix is much clearer. Figure 1 gives two original fabric images (one is tabby and the other one is twill) and shows their parallel weft direction information after using Sobel operator.



(a)Original tabby image (b)Weft direction information



(c)Original twill image (d)Weft direction information

Figure 1. Original fabric images and their weft direction information

IV. IMPROVED SKEW DETECTION ALGORITHM BASED ON HOUGH TRANSFORM

A. Hierarchical Hough transform

The advantage of Hough transform is its anti-noise ability. It is not limited by the direction of straight line in image and has good robustness. But there is a key problem about how to solve the contradiction among the accuracy, computing complexity and storage space requirements when we apply Hough transform. To solve this problem, we adopt hierarchical Hough transform to reduce the algorithm complexity. A possible skew angle scope is gained by Hough transform in low-resolution angle firstly. Then the resolution is improved in order to estimate the skew angle to get a satisfying precision. The required accuracy is achieved step-by-step from the approach finally. The low-resolution angle adopted is 1°, the high-resolution angle adopted is 0.1°.

B. Determine the search region

In order to detect any skew angle of fabric image, we search the skew angle within the scope of +90 ° to -90 °, and limit the search range with θ_l-2°to θ_l+2°for getting a more precise skew angle when use the second class Hough transform.

C. Eliminate the pseudo-extremum

Hough transform may bring the phenomenon of pseudo-extremum [4]. As a straight line corresponds to a point in parameter space according to the principles of Hough transform. In the parameter space there may be a local maximum, and the local maximum does not necessarily correspond to a weft boundary in fabric image. Thus, we vote the accumulative matrix of given angle with all the lines of weft boundary. What's more, we improve the common method of only searching for the maximum of accumulative matrix, but in search of several larger value of accumulative matrix. In many experiments, we arrange the data of the accumulative matrix from large to small, and found the value of several (usually about 10) previous data are much closer to the precise value, but the value of back data deviate from the precise value. According to the analysis of experimental results, the average value of the first ten θ of accumulative matrix is chosen. The algorithm not only effectively inhibits the noise of pseudo-extremum, but also reduces the negative influence which caused by diffused peak value.

D. Skew detection algorithm

Based on the above points, we can improve the Hough transform as follows:

(1) Set up a discrete parameter space between the appropriate maximum and minimum of the ρ and θ;

(2) Establish a accumulative matrix $A(\rho,\theta)$, and set every element to 0;

(3) Select each target pixel (x, y) of image, and take value of each θ to be θ', calculate $\theta'=x'\cos\theta'+ y'\sin\theta'$, and the corresponding accumulative matrix $A(\rho,\theta)=A(\rho',\theta')+1$(That is, the value of element $A(\rho',\theta')$ in matrix A increase the value of one);

(4) Determine the legality of maximum in accumulative matrix. Although real straight lines do not exist in fabric images, but the weft direction has strong directivity. Therefore, the accumulative matrix $A(\rho,\theta)$ has a local larger value corresponding to a certain line θ'. So we set an appropriate threshold T, which is defined as:

$$T=\lambda \max A(\rho,\theta) \quad (2)$$

Here $\lambda< 1$, then transform the $A(\rho,\theta)$ by applying the threshold as follows:

$$\text{When } A(\rho,\theta)\leq T,\ A(\rho,\theta)=0 \quad (3)$$

In this way, the interference caused by shorter line segment can be eliminated. Finally, the $A(\rho,\theta)$ on the column is accumulated in order to obtain $A'(\theta)$. Thus, the angle which the largest element of $A'(\theta)$ corresponding to is the skew angle.

(5) Eliminate the pseudo-extremum. Considering Hough transform may bring the phenomenon of pseudo-extremum, accumulative voting method is adopted to eliminate the

effect of pseudo-extremum. After accumulating the accumulative matrix A which has been verified the legality, we find out the average value of the first ten θ which corresponding to the value of accumulative matrix arranged from large to small in accumulative matrix. And this average value is the value of skew angle of the fabric image.

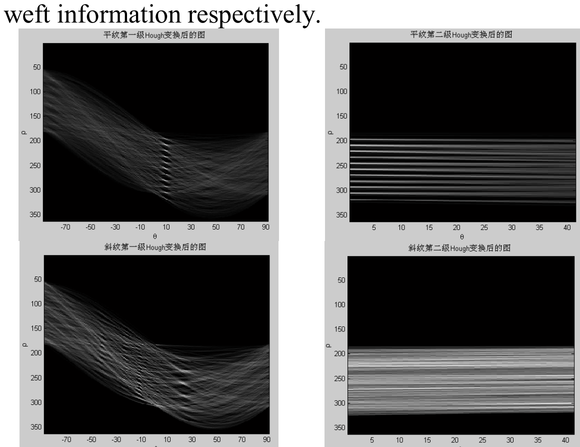
The skew angle detection algorithm of fabric image can be summarized as the following steps:

(1) Select the subregion. Obtain a subregion from the fabric image, and the further transformations are all based on this subregion.

(2) Extract the horizontal edge. Utilize Sobel operator to extract the weft boundary of the subregion, and the further transformations are all based on these edges.

(3) Carry out the first stage Hough transform in the range of -90° ~ +90°, and obtain the skew angle θ_1 from the matrix $A_1(\rho,\theta)$.

Carry out the second stage Hough transform in the range of θ_1-2°～θ_1+2°, and obtain the skew angle θ_2 from the matrix $A_2(\rho,\theta)$. Thus, θ_2 is the skew angle of the image. Figure 2 shows the results of two-stage Hough transform of the weft information respectively.



(a)The first stage Hough transform of tabby image (b)The second stage Hough transform of tabby image (c)The first stage Hough transform of twill image (d)The second stage Hough transform of twill image

Figure 2. The results of two-stage Hough transform of the weft information

V. FABRIC IMAGE SKEW CORRECTION

Skew image can be corrected after the skew angle of the fabric image is detected. Rotation transform always adopted in skew image correction as:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \tag{4}$$

$(x, y)^T$ and $(x', y')^T$ are coordinates corresponded to the same pixel point, while $(x', y')^T$ is the coordinate of $(x, y)^T$ after rotation. $\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$ is the rotation matrix.

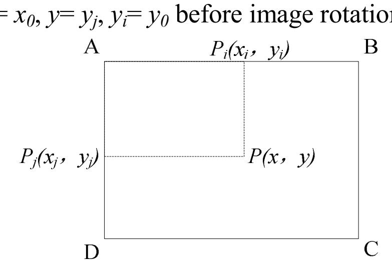
Based on the above calculation results, we can obtain the position of any pixel point of skew image after rotation. However, the rotation coordinate which is calculated by formula(4) is not integer generally, while computer only save integral coordinate of the pixel in image. So the gray value of the image can hardly get accurately even the rotation coordinate of the pixel is in the original image. Thus, interpolation operation must be adopted after image rotation.

Nearest-neighbor interpolation and bilinear interpolation are interpolations normally used. Although the speed of these interpolations is quick and algorithm is simple, the interpolations have poor effect. Block effects will appear or images will become fuzzy when use these interpolations. In order to ensure the quality of images for the further research on image analysis, by comparing the frequency domain characteristics of nearest-neighbor interpolation, linear interpolation, cubic B-spline interpolation and ideal interpolation, we find the frequency domain characteristic of cubic B-spline interpolation and ideal interpolation are closer. Thus, cubic B-spline interpolation can improve the precision of interpolation [5]. However, the computational complexity of cubic B-spline interpolation is large. If rotation matrix is calculated directly, when the computing time of the sine and cosine operations is T, image size is X×Y, then the computing time of the rotation is 4XY×T. Thus, the calculation time of skew correction is long.

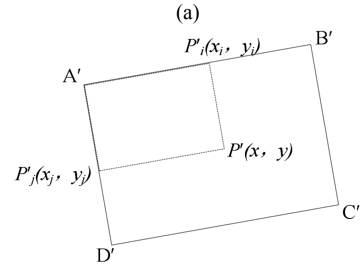
An improved image rotation algorithm is proposed to reduce the computational complexity. Since digital image is based on the linear memory construction, the relative position of pixel points is fixed. The image is defined on a rectangular domain *ABCD* which is illustrated in Figure 3(a). Four points are get from the image, one of them is any pixel point named $P(x, y)$, the second pixel point is on the same column and the first row named $P_i(x_i, y_i)$, the third is on the same row and the first column named $P_j(x_j, y_j)$, the last one is on the first row and the first column named $A(x_0, y_0)$. These four pixel points are the vertices of the rectangular. Any vertex coordinate of the rectangular can be confirmed by the other three vertices in any coordinate system:

$$\begin{cases} x = x_i + \left(x_j - x_0\right) \\ y = y_i + \left(y_j - y_0\right) \end{cases} \tag{5}$$

$x = x_i$, $x_j = x_0$, $y = y_j$, $y_i = y_0$ before image rotation.



(a)



(b)

Figure 3. Positional relationship of image before and after rotation

As the shape of rectangular and the relative position of pixel points are fixed before and after rotation transform. Figure 3(b) shows the coordinate of the four vertices A, P_i, P_j, P of the rotation rectangular corresponding to the points A', P_i', P_j', P' is still meet as:

$$\begin{cases} x = x_i + \left(x_j - x_0\right) \\ y = y_i + \left(y_j - y_0\right) \end{cases} \tag{6}$$

Therefore, the rotation result of all pixel points can be calculated based on the rotation result of the pixel points on the first row and the first column. So we only need to transform the pixel points on the first row and the first column as formula(4) to formula(6) to correct the image. To the other pixel points, addition and subtraction operations as formula(6) are enough. The computing time of skew image rotation transform is 4(X+Y)×T. Thus, the execution efficiency of rotation transform is improved.

VI. EXPERIMENTAL RESULT ANALYSIS

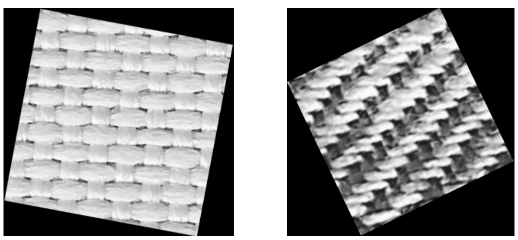


Figure 4. The results of skew tabby and twill fabric image after skew correction

Figure 4 shows the results of skew tabby and twill fabric image after skew correction. Detected skew angle of original tabby image using the traditional standard Hough transform is 11.13° and the improved detection algorithm of this paper is 10.60°, while the actual skew angle is 10.45°; Detected skew angle of original twill image using the traditional standard Hough transform is 26.41° and the improved detection algorithm of this paper is 25.87°, while the actual skew angle is 25.87°.

Table I tabulates the processing time required to detect the skew angle of the above two images using the traditional standard Hough transform and the improved detection algorithm of this paper.

TABLE I. TIME REQUIRED FOR THE SKEW ANGLE DETECTION

Image	Traditional Hough transform(s)	improved detection algorithm(s)
tabby fabric image	1.326	0.418
twill fabric image	1.353	0.472

In order to test the accuracy of the improved detection algorithm, we tilt the twill fabric image at eight angles from -75° to 75°, and then use the improved detection algorithm to detect the skew angle of the image separately. Table II shows the results of skew angles achieved by the improved detection algorithm. It can be seen from the table that the average error of the algorithm is 0.23° while the maximum errors were less than 0.4°, and the average accuracy rate is 99.26%. These data indicate that the skew angles detected by the improved detection algorithm with higher accuracy. Experimental results show that the use of weft direction information of fabric image and the improved Hough transform algorithm to detect the skew angle can improve the accuracy and interference immunity, and greatly reduce the execution time. Thus, the improved detection algorithm is capable of solving the skew problem in practical applications.

TABLE II. ALGORITHM ACCURACY TEST

Actual angle(degree)	Detected angle(degree)	Error(degree)	Accuracy(%)
-75	-74.67	0.33	99.56
-55	-55.19	0.19	99.65
-35	-35.16	0.16	99.54
-15	-15.27	0.27	98.20
15	14.75	0.25	98.33
35	35.09	0.09	99.74
55	55.38	0.38	99.31
75	74.82	0.18	99.76

VII. CONCLUSIONS

A Hough transform based approach is proposed to automatically detect skew angles of fabric images and correct them. To develop an algorithm with high accuracy and with the ability of dealing with fabric images of different texture information, Sobel operator is introduced to extract the weft direction information before applying two-stage Hough transform. After skew detection, a rotation algorithm based on the image linear storage structure is also adopted to correct the skew image rapidly. Experimental results on various types of fabric images show that the improved detection method has achieved a promising performance and a high accuracy for detecting skew angle of fabric images. What's more, the proposed method can successfully detect skew angles of different texture information, without the skew angle limitation. Therefore, it can meet the needs of practical applications.

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