Automatic slub detection using Gabor filters

Xiuping Liu, Zhijie Wen, Zhixun Su and Shaogeng Yi
Department of Applied Mathematics, Dalian University of Technology, Dalian, People's Republic of China

Received 8 April 2007
Revised 28 September 2007
Accepted 28 September 2007

Abstract

Purpose – Automatic slub detection is vital in the classification and identification of fabric images. This paper seeks to present a rapid and accurate approach for automatic detection of slub in fabric images using Gabor filters.

Design/methodology/approach – Slub can be regarded as defects along weft or warp. Gabor filters as bandpass filters consider the directional characteristics of slub and its frequency spectrum after Fourier transform. Choosing appropriate parameters for Gabor filters, slub can be detected accurately.

Findings – The proposed method achieves automatic detection of slub. The experimental results suggest that the authors approach is effective.

Originality/value – This paper considers appropriate parameters to design a Gabor filter for automatic detection of slub. And it is helpful to classify and identify fabric images.

Keywords Textile industry, Image processing, Error handling

Paper type Research paper

Introduction

Slub-yarn is a sophisticated yarn, whose slub appearance is gained via the variation of the yarn linear density during the spinning process and because of its special appearance, has been widely used in a variety of garments. The mechanical properties of slub-yarns, including the twist distribution, were analyzed in the past (Lu *et al.*, 2006). Most of the studies on the slub-yarn concentrate on its parameters and the principle of formation (Wang and Huang, 2002), but slub detection often belongs to defect detection in textile materials stated by some researchers (Kumar and Pang, 2002; Zhang and Breese, 1995; Chan and Pang, 2000), and it is hard to achieve automation. In the fabric industry, conventional means of detecting slub usually adopt indirect testing and contrasting to the real fabric sample. These manual operations are usually tedious, time-consuming and easily tire an operator's eyes. In our method, automatic slub detection is proposed. Moreover, we can get the parameters of slub according to the detecting results, such as slub length and intervals, etc. which are very important to the classification and identification of fabric images.

Since a woven fabric can be regarded as a typical periodic image, Fourier transform is useful to analyse it (Xu, 1996; Su *et al.*, 2006; Ravandi and Torimi, 1995). The peaks in the frequency domain after Fourier transform characterize periodicity of fabric image. Slub destroys the periodicity of the fabric and can be regarded as defects along the weft or warp. However, 2D Gabor filters have been shown to be particularly useful for

This work is supported by National Natural Science Foundation of China (60673006), New Century Excellent Talents in University of China (No. NCET-05-0275).

The authors would like to thank the anonymous reviewers for their useful comments.

International Journal of Clothing Science and Technology
Vol. 20 No. 4, 2008
pp. 214-221

0955-6222
DOI 10.1108/09556220810878838

analyzing texture images containing highly specific frequency or orientation characteristics (Dunn and Higgins, 1995; Bovik *et al.*, 1990; Jain and Farrokhnian, 1991). They have been applied by Kumar and Pang (2002) to detect defects in textured materials and by Dunn and Higgins (1995) to segment texture. The 2D Gabor filters are multi-channel filters and are appropriate for textural analysis in several senses: they have tunable orientation and radial frequency bandwidths, and can achieve optimal joint localization in spatial and frequency domain.

In the next section, a review of Gabor filters is presented, including the characteristic in the frequency domain of a typical periodic image after Fourier transform. Followed by the section that describes the slub detection method. The next section gives the experimental results, which are followed by the conclusion in the penultimate section.

Gabor filters

Gabor channel functions

Inspired by the multichannel operation of the human visual system (HVS) for interpreting texture, research has been focused on using a multichannel approach based on Gabor filtering to simulate the operation of HVS for texture regions. Simple cells in the visual cortex were found to be sensitive to different channels of combinations of various spatial frequencies and orientations (Tan, 1995). Moreover, Gabor filters achieve optimal joint localization in spatial and frequency domain (Daugman, 1985). As mentioned above, Gabor filters can decompose the image into component images corresponding to different scales and orientations. Therefore, they have been used extensively for texture analysis (Dunn and Higgins, 1995; Bovik *et al.*, 1990; Jain and Farrokhnian, 1991) and defect detection (Kumar and Pang, 2002).

Gabor transform was first defined by Gabor (1946) and later extended to 2D by Daugman (1985). In the spatial domain, the Gabor function is a Gaussian modulated by a complex sinusoid:

$$h(x,y) = g(x',y') \cdot \cos(2\pi j(Ux + Vy)), \tag{1}$$

where $(x',y') = (x\cos\phi + y\sin\phi, -x\sin\phi + y\cos\phi)$. U and V are frequencies along the x- and y- axes, and:

$$g(x,y) = \frac{1}{2\pi\lambda\sigma^2}\exp\left[-\frac{(x/\lambda)^2 + y^2}{2\sigma^2}\right],$$

where $\lambda(\lambda = \sigma_x/\sigma_y)$ is the aspect ratio of Gaussian function, while σ_x and σ_y characterize the spatial extent and bandwidth of the filter, respectively. $F = \sqrt{U^2 + V^2}$ (cycles/image width) is the radial center frequency and the orientation is $\theta = \tan^{-1}(V/U)$ (degrees or radians measured from u-axis). It is usually convenient to consider filters whose modulating Gaussians have the same orientation as the complex sine grating ($\phi = \theta$). In this case, the Gabor function (1) reduce to:

$$h(x,y) = g(x',y') \cdot \cos(2\pi jFx'). \tag{2}$$

In the frequency domain, Fourier transform of the Gabor functions is:

$$\begin{aligned} H(u,v) = {} & \frac{1}{2}\exp\{-2\pi^2\sigma^2[(u'-F)^2\lambda^2 + (v')^2]\} \\ & + \frac{1}{2}\exp\{-2\pi^2\sigma^2[(u'+F)^2\lambda^2 + (v')^2]\}, \end{aligned} \tag{3}$$

where $(u', v') = (u\cos\phi + v\sin\phi, -u\sin\phi + v\cos\phi)$. Thus, the Gabor frequency response has the shape of two Gaussians. One of the Gaussian's major and minor axis widths are determined by σ_x and σ_y, it is rotated at an angle θ from the positive u-axis and centered about the frequency (U, V). Thus, Gabor filters act as bandpass filters. Figure 1 shows intensity plots of several 2D Gabor functions having this "daisy petal" configuration. There are a total of 40 different Gabor filters with $\lambda = 0.5, B = 0.6, F = [4, 8, 16, 32, 64]$, $\theta = k\pi/8, k = 0, 1, \ldots, 7$. When $\lambda = 1$, Gabor filters are symmetric filter. Because most of real fabric images contain textels (Kumar and Pang, 2002) not arranged in a square lattice, asymmetric Gabor filters are more useful.

For a given input image $I(x, y)$, the magnitude of filtered image $f(x, y)$ is:

$$f(x, y) = I(x, y) \times h(x, y), \tag{4}$$

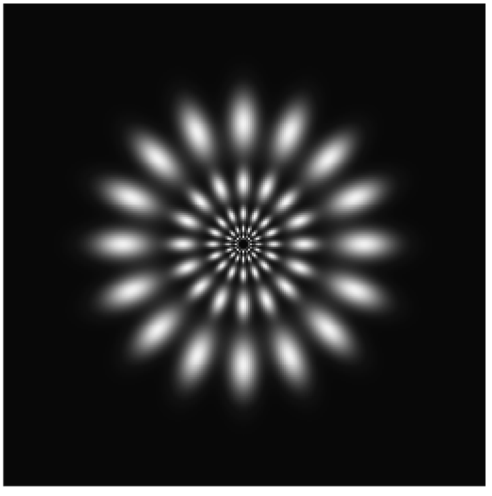
where $h(x, y)$ is the Gabor filter defined in equation (2).

Properties of Gabor filters

The crucial step in the application of Gabor filters is the choice of the filter parameters. There are large numbers of papers stating approaches of parameters choosing (Kumar and Pang, 2002; Dunn and Higgins, 1995). The parameters of Gabor filters are usually chose after consideration of spatial frequencies and orientations of detected features. The radial frequency bandwidth B is defined as:

$$B = \log_2\left[\frac{(\pi F\lambda\sigma + \alpha)}{(\pi F\lambda\sigma - \alpha)}\right] \text{ (octaves)}, \tag{5}$$

where $\alpha = \sqrt{(\ln 2)/2}$. By varying the free parameters of B, F, θ, λ, Gabor filters with arbitrary orientation and bandwidth characteristics can be generated by spanning any oval region of the frequency domain.



Notes: There are a total of 40 Gabor filters. The origin is at (row, col) = (128,128)

Figure 1.
The filter set in the frequency domain (256×256)

The most important property of Gabor filters is that they are sensitive to the orientation of detected features, which is shown by the model image in Figure 2. The directional analysis algorithm developed using Gabor filters consists of the following steps: first, generate a set of Gabor filters (in the spatial domain) tuned to a set of angle bands. Then, convolve the Gabor filters with the given image, which results in a set of component images, one for each angle band. For example, we programme a Gabor filter to 90°. The filtered image is shown in Figure 2. From this example, we can find that Gabor filter is useful to analyze the directional features in the image.

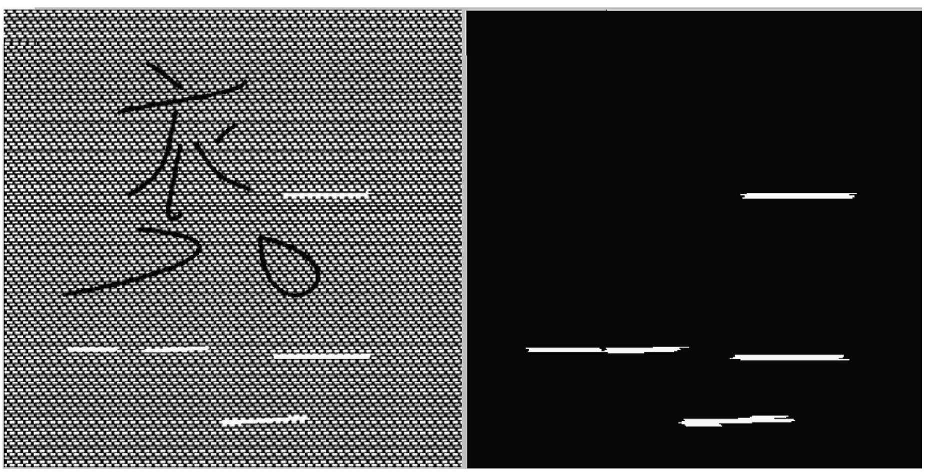
Slub detection algorithm

Choice of filter parameters

There are two kinds of implementations of Gabor filters, one in the spatial domain, and the other in the frequency domain. According to equation (2), we first decide four parameters λ, σ, ϕ, F to make the filter fit to the specific texture image, and then convolve the image with the chosen filter. But it is hard to find proper σ, F in the spatial domain. In order to choose parameters easily, we implement filtering process in frequency domain. Owing to the convolution theory of Fourier transform, it follows that:

$$I(x,y) \times h(x,y) = \mathrm{ifft}(F(u,v)H(u,v)) \quad (6)$$

where ifft is the inverse Fast Fourier transform. Then we just need to obtain the parameters σ, F, θ, λ. As the textels (Kumar and Pang, 2002) in real fabric image are not arranged in a square lattice, let $\lambda = 0.5$. F is obtained by the following operations. We must first inspect the characteristic of the frequency spectrum of slub-yarn. For a fabric image without slub, its frequency spectrum has six centrosymmetric peaks during one period after eliminating the central peak. The values and location of peaks (high-magnitude areas) reveal the periodicity and orientation of the periodic structure in the fabric image, respectively, (Su *et al.*, 2006). For the slub-yarn, its frequency



(a) (b)

Figure 2. Model image and the segmentation of filtered image with the Gabor filter at 90°

spectrum has more peaks around the center corresponding to slubs (enclosed by ellipse in Figure 3(b)) except for the six peaks mentioned above. We only need to choose the location of the maximum among these peaks as the central frequency and the orientation (warp or weft) as the orientation of the chosen filter (Figure 3(c)). Moreover, the location of central frequency is similar for the different slub-yarn. Finally, set B to the empirical data 2. σ is obtained by formula $\sigma = (\alpha(2^B + 1))/(\pi F \lambda(2^B - 1))$ deducted from equation (5). And slubs in the real fabric samples are distributed along warp ($\theta = 0$) and weft orientation ($\theta = \pi/2$). They are substantially thicker than individual yarns in the fabric, so they can be regarded as directional defects in the fabric. Taking advantage of the bandpass technique of Gabor filters, this approach can restrain the frequency component of the normal texture in the fabric, and strengthen the frequency component of slubs. The parameters are similar for different slub-yarn, so our method achieves the detection of slub automatically. Figure 4 shows the detection result of Figure 3. The left image shows successful slub detection. For exhibiting the accuracy of our method, we also show the overlay result (obtained by covering original image with slub image) on the right. More experimental results are shown in the next section.

The implementation of algorithm

The slub detection algorithm developed using Gabor filters consists of the following steps:

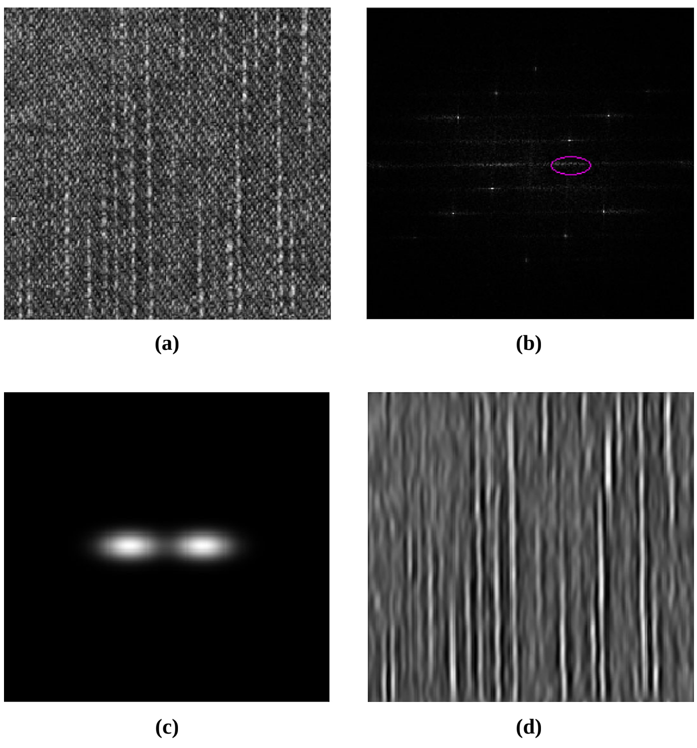


Figure 3.
(a) Original image; (b) frequency spectrum after Fourier transform; (c) filter shape with parameters chosen above; (d) the filtered image

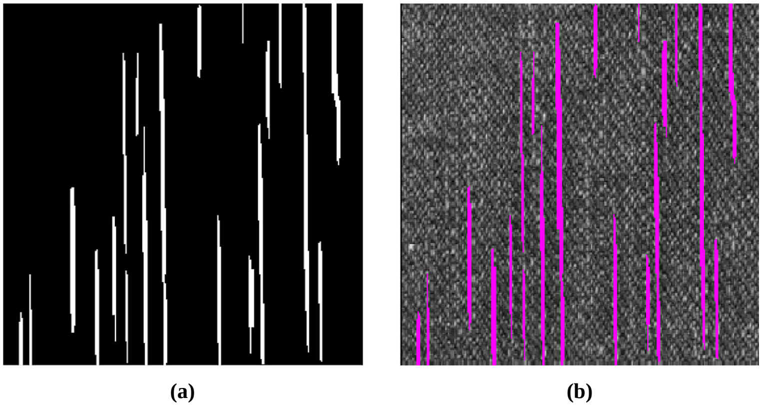


Figure 4. (a) Slub image; (b) overlay results

(1) Get the frequency spectrum $F(x, y)$ of a real fabric image sample $I(x, y)$ which is transformed by FFT.
(2) Choose the parameters σ, F, θ, λ of Gabor filter $H(u, v)$ for equation (3).
(3) Generate the filtered image by the following operation:

$$f(x,y) = \mathrm{ifft}(F(u,v)H(u,v))$$

where ifft is the inverse Fast Fourier transform.
(4) Get the threshold according to the histogram of the filtered image.
(5) Remove the unwanted spectral components from the filtered image obtained in Step (3).
(6) Using morphological operations to eliminate the noise in the image obtained in Step (5), we finally get the slub distribution image finally.

Experimental results

The performances of slub detection described in the above section are evaluated on fabric samples in Figure 5. The left images in Figure 5 are the images containing slub, the middle images are the original images. The overlay results are shown on the right in Figure 5. From overlay results, we can see the efficiency of our approach. Because we just choose one filter to deal with one image, this method is rapid too.

In this experiment, 32 real fabric samples are used to examine our method. The efficiency of this approach is illustrated with 99 percent accuracy in slub detection. According to the detection results, we can get the parameters of slubs, for example, slub length, slub intervals, etc. These parameters can be trained with a self-organizing feature map. The networks have different output maps for different input states, which can be used for classifying slub-yarns.

Conclusion

In our paper, an approach for automatic identification of slub defects is studied. The approach is based on Gabor filters, which are bandpass filters and sensitive to the

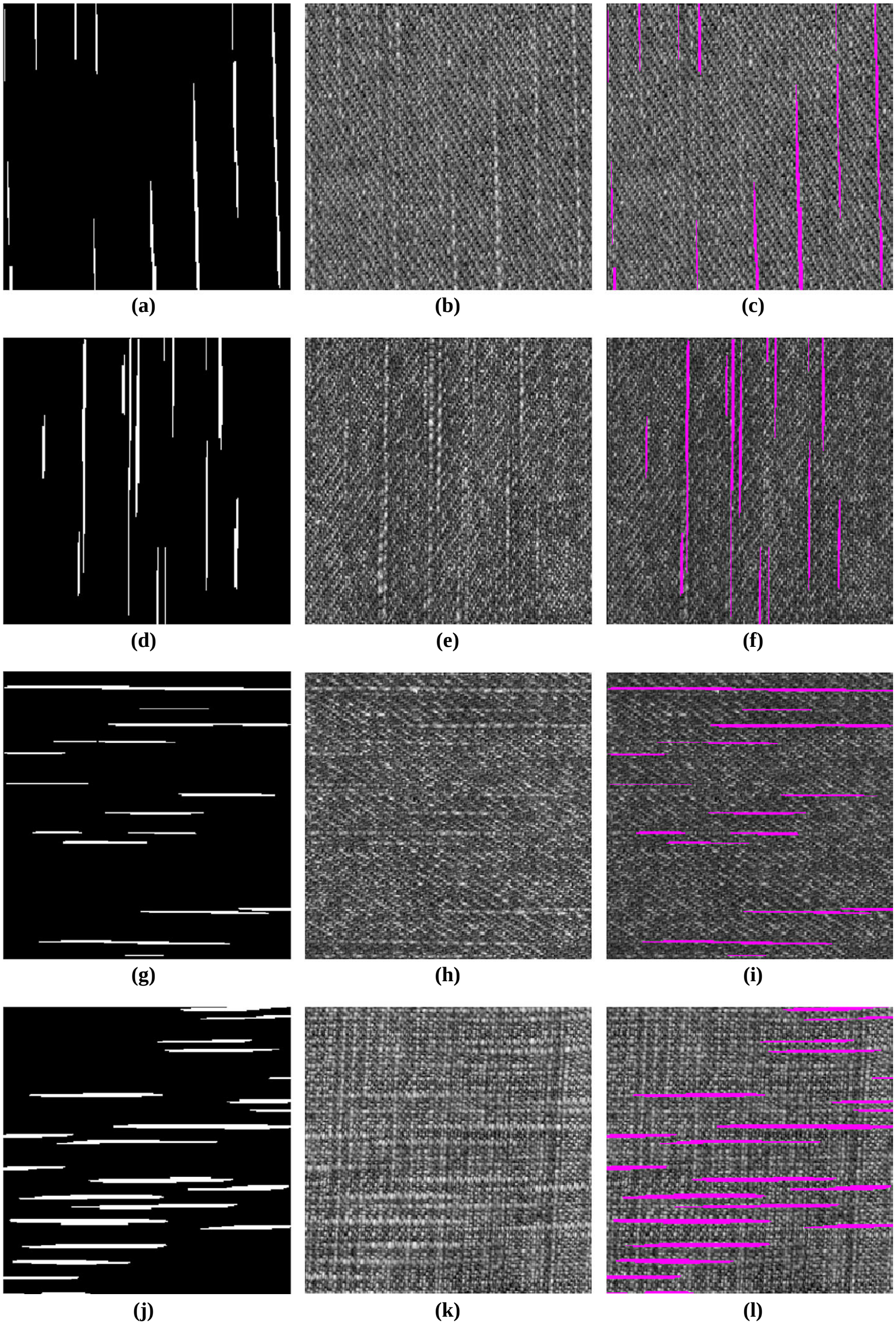


Figure 5.
Figure 5 (b), (e), (h), (k): fabric samples with slub; (a), (d), (g), (j): corresponding segmented images with slub using a Gabor filter; (c), (f), (i), (l): overlay results

directional features in the image. Regarding slubs as directional defects, we choose the Gabor filter to detect them in the slub-yarn. At last, this paper confirms the performance of the proposed method by testing 32 real fabric samples.

References

Bovik, A.C., Clark, M. and Geisler, W.S. (1990), "Multichannel texture analysis using localized spatial filters", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 12 No. 1, pp. 55-73.

Chan, C.H. and Pang, K.H. (2000), "Fabric defect detection by Fourier analysis", *IEEE Transactions on Industry Applications*, Vol. 36 No. 5, pp. 1267-76.

Daugman, J.G. (1985), "Uncertainty relations for resolution in space spatial frequency and orientation optimized by two-dimension visual cortical filters", *Journal of the Optical Society of America*, Vol. 16 No. 2, pp. 1160-9.

Dunn, D. and Higgins, W. (1995), "Optimal gabor filters for texture segmentation", *IEEE Transactions on Image Processing*, Vol. 4 No. 7, pp. 947-64.

Gabor, D. (1946), "Theory of communication", *Journal of the Institute of Electrical Engineers*, Vol. 93 No. 26, pp. 429-57.

Jain, A.K. and Farrokhnia, F. (1991), "Unsupervised texture segmentation using Gabor filters", *Pattern Recognition*, Vol. 24 No. 12, pp. 1167-86.

Kumar, A. and Pang, G. (2002), "Defect detection in textured materials using Gabor filters", *IEEE Transactions on Industry Application*, Vol. 38 No. 2, pp. 425-40.

Lu, Y.Z., Gao, W.D. and Wang, H.B. (2006), "A model for the twist distribution in the slub yarn", *International Journal of Clothing Science & Technology*, Vol. 19 No. 1, pp. 36-42.

Ravandi, S.A.H. and Toriumi, K. (1995), "Fourier transform analysis of plain weave fabric appearance", *Textile Research Journal*, Vol. 65 No. 11, pp. 676-83.

Su, Z.X., Wen, Z.J., Qiao, W.S., Yi, S.G. and Shi, X.Q. (2006), "Automatic identification of the fabric structure based on Fourier transform", *Journal of Information and Computer Science*, Vol. 3 No. 3, pp. 527-34.

Tan, T.N. (1995), "Texture edge detection by modeling visual cortical channels", *Pattern Recognition*, Vol. 28 No. 9, pp. 1283-98.

Wang, J. and Huang, X.B. (2002), "Parameters of rotor spun slub yarn", *Textile Research Journal*, Vol. 72 No. 1, pp. 12-16.

Xu, B.G. (1996), "Identifying fabric structure with Fourier transform technique", *Textile Research Journal*, Vol. 66 No. 8, pp. 496-506.

Zhang, Y.X. and Breese, R.R. (1995), "Fabric detection and classification using image analysis", *Textile Research Journal*, Vol. 65 No. 1, pp. 1-9.

Corresponding author
Zhijie Wen can be contacted at: wenzhij_cn@163.com