FULLY AUTOMATIC APPROACHES FOR CROSSED-POINTS DETECTION IN WOVEN FABRIC RECOGNITION

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Abstract: *Fabric analysis is done to determine fabric weave patterns used in the weaving process. The analysis of fabric-weave patterns still relied on human inspection until the middle of the 1980s. Since then, a number of studies have been made of automatic pattern recognition of woven fabric. One of the major problems in automatic woven fabric recognition is bow to detect the areas of interlacing warp and weft yams. This problem is termed 'crossed-points detection', the difficult problem. In this work, new and fully automatic methods containing Otsu, Isodata, Li, Mean Minimum, Triangle and Yen thresholding algorithms and based on Fourier image-analysis techniques as well are proposed. The application of these methods to plain woven fabric demonstrates the ability to solve such crossed-points-detection problems. Finally, the algorithms are evaluated visually by superposing the detected grid image on the initial woven-fabric image. Grid images obtained by Otsu and Isodata thresholding methods involve the crossed points better than other methods. Besides, vertical lines that extracted with Li method are more left than lines that detected using other methods. Moreover, results from Mean method is close results of Otsu and Isodata. Similarly, Mean and Minimum method's result is close to results of Otsu and Isodata. In Triangle and Yen methods, while horizontal lines are extracted, vertical lines are not extracted. All the detected crossed-points are displayed independently and may be saved as file-format images for further processing.*

Key words: *Woven fabric recognition, fabric weave patterns, Fourier image analysis, crossed-points detection, texture analysis.*

1. INTRODUCTION

Fabric analysis is done to determine fabric weave patterns used in the weaving process. A woven fabric made of the cross combination of warp and weft yams has a two-dimensional lattice structure [1]. In determining fabric-weave patterns, there are two questions to answer: (i) How can we detect the areas of the interlacing warp and weft yams? This problem is termed 'crossed-points detection'. In the crossed-points areas, it is useful to observe that there are two possible states: warp over weft yam or weft over warp yam. Then the second question is: (ii) How can we detect which yam is over the other in this area? This problem is termed 'crossed-states detection'. This study aims at answering the first question, whereas the problem posed in the second question will be investigated in further work.

The analysis of fabric-weave patterns still relied on human inspection until the middle of the 1980s [1]. Since then, a number of studies have been made of automatic pattern recognition of woven fabric. In 1989, Kinoshita et al. determined the type of weave patterns in woven fabric by analysing two-dimensional Fourier-transform patterns of the reflected image. They established some relationships between the structural units of weave type and weave-power spectra. In 1996, Bugao Xu discriminated between the weave patterns based on the analysis of radial and angular histograms of the corresponding power spectra. These two methods (Kinoshita et al., 1989; Xu, 1996) are global in the sense that they make a discrimination of fabric-weave patterns without analysing the states of the crossed points [1],[2]. Consequently, these methods do not allow us to draw a diagram of a woven fabric from the analysis of a real one. Other methods were by Ohta et al. (1986), and Tae Jin Kang et at. (1999) [3],[4]. In their work, the problem of crossed-points detection is only solved for simple woven fabrics (without skewness or design) by using image-analysis techniques. Furthermore, Ohta's method needs a series of dilatation and thinning processes that must be stopped interactively by making subjective judgment or visual control by the user. This method requires a prior measure of warp- and weft-yams width, which also presents another inconvenience.

Tae Jin Kang's method (1999) uses two image acquisitions, a transmissive one and a reflective one. In the transmissive image, dark areas indicate the location of warp and weft yams; and bright spots represent the spaces between interlacing yams since light cannot be transmitted through the yams. The transmissive image of the woven fabric is converted to a binary image, and the positions of white-pixel objects are found after the central co-ordinates of white pixels are connected horizontally and vertically. Then, an initial grid image is made, error lines are removed, and missing lines are inserted. Finally, the data set of crossed-points is completed. Compared with Ohta's method, this procedure is fully automatic and does not require any subjective visual control. Unfortunately, it presents two problems. The first one is that it requires two image acquisitions. The second, as was mentioned by Tae Jin Kang, is the demand for appropriate alignment of yams parallel and perpendicular to the image axes.

From the above critical remarks of Ohta's method and Tae Jin Kang's procedure, it appears that the problem of crossed-points detection remains a difficult task for simple woven fabric. This problem is still unsolved for woven fabric with skewness or non-periodic design. To overcome this problem, we propose new and fully automatic methods containing Otsu, Isodata, Li, Mean Minimum, Triangle and Yen thresholding algorithms for crossed-points detection based on Fourier image-analysis techniques.

2. MATERIAL AND METHOD

In this study, the image of yarn-dyed plain-woven fabric was captured by Canon EOS 550D 18.0 megapixel digital single-lens reflex camera with ISO-800, 5.6 f-step, shutter speeds of 1/60th of second and RGB true colour mode. With the size of 500 x 500 pixels, a yarn-dyed fabric image including one kind of colour yarn is shown in image (a) in **Fig.** . During the recognition process, all the woven fabric images used in this paper are shown in image (a) in **Fig.** .

The Visual Studio Code 1.33.0 and Python 3.7.2 were used as the software tool to examine the process, and the CPU of the computer used in the experiment is Intel Core i5-2400 CPU 3.10GHz. The computer has 12.0 GB ram, and runs on Microsoft Windows 10 Build 1809. Pyplot module from Matplotlib 3.0.2 providing a MATLAB-like interface was used for plotting images and spectrums. Pyplot is a Matplotlib module which NumPy (Numerical Python) 1.16.1 package, a math library, allowing us to do scientific calculations quickly was used for scientific computing.

Image processing algorithms in Scikit-Image 0.14.2 containing algorithms for filtering, morphology, analysis, feature detection, segmentation, geometric transformations, colour space manipulation, and more were used. It is designed to work as integrated with Python numerical and scientific libraries NumPy and SciPy, respectively.

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$$I_Y = 0.2125I_R + 0.7154I_G + 0.0721I_B \quad (1)$$

2-D discrete Fourier transform (DFT):

$$F(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} \quad (2)$$

where $f(x,y)$ is a digital image of size M x N.

2-D inverse discrete Fourier transform (IDFT):

$$f(x,y) = \frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} F(u,v)e^{j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} \quad (3)$$

for x = 0,1,2, ..., M - 1 and y = 0,1,2, ..., N -1.

$F(u,v)$ is a function that generally returns complex value and its Power Spectrum is an observable real valued function, which is defined in **Eq. (4)**. Because of limitations of most image-display systems like Matplotlib, the transform in **Eq. (5)** was used in this paper.

$$P(u,v) = |F(u,v)|^2 \quad (4)$$

$$D(u,v) = log\{1 + P(u,v)\} \quad (5)$$

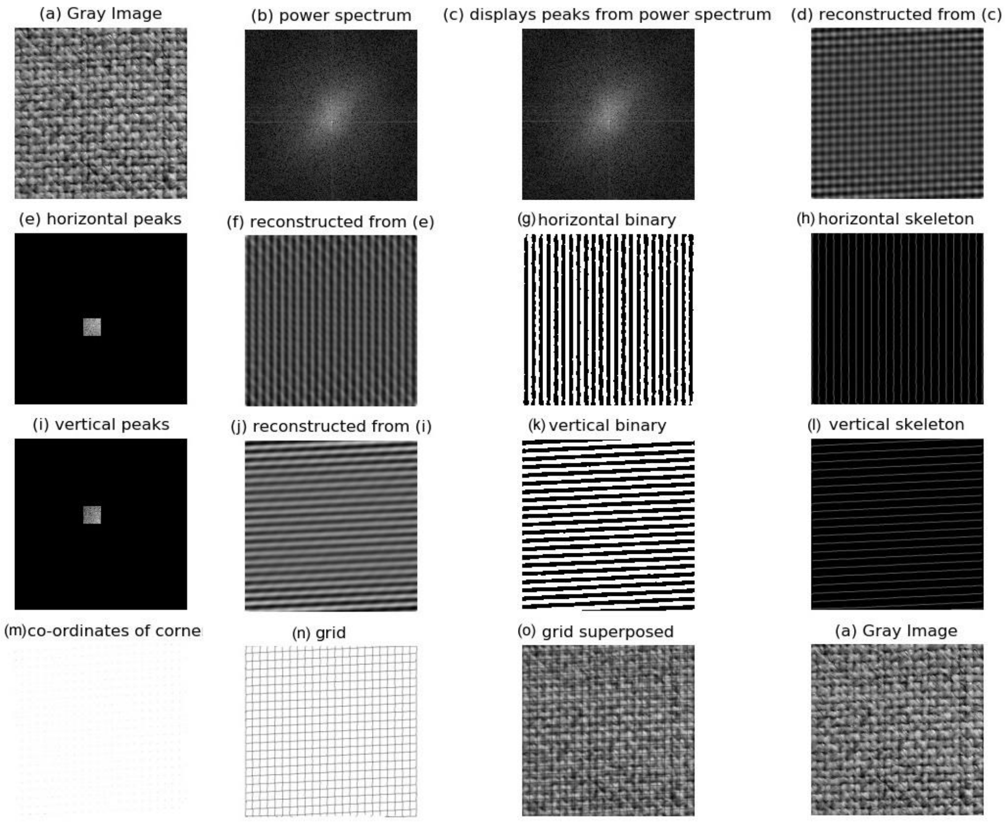

Fig. 1: *Images of detected warp, weft yarn from plain fabric weave image and crossed points of yarns*

2.1. Detection of Warp and Weft Yarns

To extract periodic yarn patterns in woven fabric image, Fourier transform was used. Frequency transform shows all periodic yarns in peaks in the power spectrum ($P(u,v)$) image. Peaks on power spectrum represents weft yarns and warp yarns. Reconstructed image that inverse Fourier transform of phases of selected peaks is illustrated warp and weft yarns. In a spectrum of weave, horizontal line peaks are related with warp yarns, and vertical line peaks are related with weft yarns. Choosing power spectrum peaks in horizontal and vertical peaks is able to detect warp and weft yarns. To make explicit the yarns from background, a threshold algorithm is proposed to use. Thresholding image is made binary the image. In order to skeletonize the yarn image, yarns are thinned to one-pixel width lines by a thinning algorithm.

Fig. shows an example to illustrate the detection of warp and weft yarns from plain woven fabric. Image (a) displays the grayscale project of original image. Image (b) and (c) represent power spectrum of grayscale image and Image (d) is reconstructed image of selected peaks of frequencies. If peaks are selected like in image (e), the reconstructed image (f) will display warp yarns. Likewise, if peaks are selected like in image (i), the reconstructed image (j) will display weft yarns.

2.2. Binarization and Skeletonization of Detected Warp and Weft Yarns

Thresholding functions change each pixel in an image with 1 (a black pixel) if the image intensity $I_{u,v}$ is less than some fixed constant t or a 0 (a white pixel) if the $I_{u,v}$ is greater than t. **Eq. (6)** constitute a simple thresholding method [5].

$$g(x,y) = \begin{cases} 1, & if\ f(x,y) > t \\ 0, & if\ f(x,y) \le t \end{cases} \quad \textbf{(6)}$$

The warp yarn lines image (g) and weft yarn lines image (k) are extracted by using seven thresholding methods. These are Otsu, Isodata, Li, Mean, Minimum, Triangle and Yen algorithms.

Otsu's algorithm tries to find a threshold value t, which minimizes the intra-class variance, defined as a weighted sum of variances of the two classes:

$$\sigma_\omega^2(t) = q_1(t)\sigma_1^2(t) + q_2(t)\sigma_2^2(t) \quad \textbf{(7)}$$

where

$$q_1(t) = \sum_{i=1}^{t} P(i), q_2(t) = \sum_{i=t+1}^{I} P(i), \mu_1(t) = \sum_{i=1}^{t} \frac{iP(i)}{q_1(t)}, \mu_2(t) = \sum_{i=t+1}^{I} \frac{iP(i)}{q_2(t)}, \sigma_1^2(t) = \sum_{i=1}^{t} [i - \mu_1(t)]^2 \frac{P(i)}{q_1(t)}, \sigma_2^2(t) = \sum_{i=t+1}^{I} [i - \mu_2(t)]^2 \frac{P(i)}{q_2(t)}$$

Isodata thresholding algorithm calculates a threshold t for a gray projected Image [6]. If mean of all pixels in image is less than or equal to t, it will be called as m_L, and if mean of all pixels in image greater than t, it will be called as m_H. Threshold t is able to find in **Eq. (8)**.

$$t = \frac{m_L(t) + m_H(t)}{2} = m(t) \quad \textbf{(8)}$$

Li's Minimum Cross Entropy thresholding method based on the iterative version of the algorithm [7],[8]. It computes threshold value by Li's iterative Minimum Cross Entropy method.

Mean thresholding method uses the mean of grey levels as the threshold [9].

$$\bar{X} = \sum_{i=0}^{n} \frac{X_i}{n} \quad \textbf{(9)}$$

Minimum thresholding method based on minimum method [10]. The histogram of image is smoothed until there are only two maxima. Then the minimum of two maxima is selected as threshold.

Triangle algorithm based on finding the grey value that gives maximum distance d [11]. d is the distance of a line is constructed between the maximum of the grey value histogram and the lowest value in the image.

Yen's thresholding method based on Yen's entropy algorithm [12]. It defines entropic correlation as **Eq. (10)**.

$$TC(T) = C_b(T) + C_f(T) = -log\left(\sum_{g=0}^{T}\left[\frac{p(g)}{P(T)}\right]^2\right) - log\left(\sum_{g=T+1}^{G}\left[\frac{p(g)}{1-P(T)}\right]^2\right) \quad \textbf{(10)}$$

Warp yarn lines and weft yarn lines are obtained by applying Skeletonize thinning algorithm to 1-pixel width warp yarn lines image (h) and weft yarn lines image (l) [13].

Lastly, the corner coordinated image (m) is acquired by intersecting image (h) and image (l). And the grid image (n) is acquired by superposing image (h) and image (l). Then image (o) is obtained by superposing grid image (n) and original image (a).

3. RESULTS AND DISCUSSIONS

In Otsu thresholding method, Horizontal lines generally pass over weft-yarns as illustrated in **Fig.** . A few lines coincide with topside or bottom-side of weft-yarns. Vertical lines are over edge of warp-yarns. Using Isodata thresholding method, Horizontal lines generally pass over weft-yarns, and vertical lines touch edge of warp-yarns as shown image (a) in **Fig.** . Image (b) in **Fig.** shows extraction of yarn lines with Li thresholding. Horizontal lines trace to middle of weft-yarns. Vertical lines pass over side of warp yarns. In Mean thresholding method, A few horizontal lines pass over middle of yarns or edge of yarns. Vertical lines generally pass over edges of yarns. It is illustrated on image (c) in **Fig. .** In Minimum thresholding method, Horizontal lines pass over topside and bottom side of yarns or edge of weft-yarns as shown image (d) in **Fig. .** Vertical lines are over left side of warp yarns. Using Triangle thresholding method, a few horizontal lines pass over topside and a few horizontal lines pass over bottom side of yarns as illustrated in image (e) in **Fig.** . Vertical lines are not able to acquire with Triangle thresholding method. Using Yen's thresholding method, A few horizontal lines pass over topside and a few horizontal lines pass over bottom side of yarns as shown in image (f) in **Fig.** . Vertical lines are not able to acquire with Yen's threshold method.

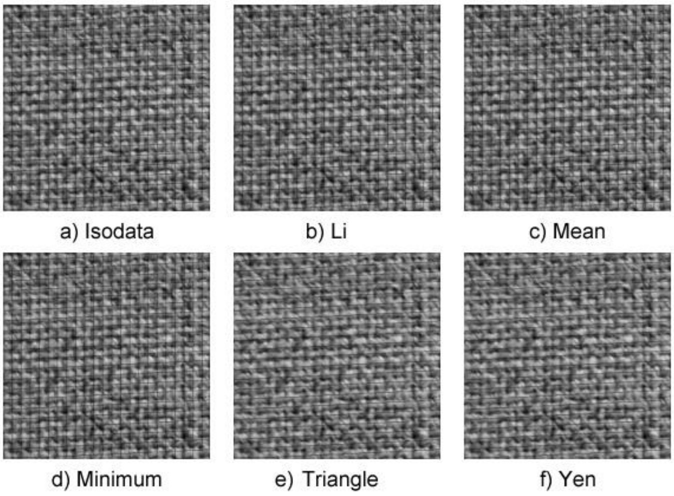

Fig. 2: *Extraction warp and weft yarns with Isodata, Li, Mean, Minimum, Triangle and Yen thresholding methods*

According to result, Threshold selection methods give close results, but Triangle and Yen methods don't give any result on warp yarns. Reconstructed image from selected peaks of power spectrum has close gray intensity value. Gray intensities of the image seem to have been collected in nearby regions on histogram. Otsu, Isodata, Li, Mean and Minimum methods are basically tried to search mean of grayscale intensity. Thence, these methods give same yarn-lines results. Triangle and Yen methods are best for images that has homogeneous gray instensity. Thence, Triangle and Yen methods is not able to give a yarn-lines result

4. CONCLUSION

To overcome the limitation of algorithms for automatic crossed-points detection by using image-analysis techniques, in this investigation fully-automatic algorithms containing Otsu, Isodata, Li, Mean Minimum, Triangle and Yen thresholding methods and also based on Fourier image-analysis techniques have been developed. By applying the proposed algorithm to woven-fabric images, crossed-points are easily detected with high precision in plain woven fabric.

Vertical line obtained by Otsu and Isodata thresholding method passing along the warp yarns, on the other hand vertical lines represent better than horizontal. The best grid images are obtained by Otsu and Isodata thresholding methods. Besides, vertical lines that extracted with Li method are more left than lines that detected using other methods. Moreover, results from Mean and Minimum method is close to results of Otsu and Isodata. Similarly, In Triangle and Yen methods, while horizontal lines are extracted, vertical lines are not extracted.

With a non-periodic design, such as flowers, which may sometimes occur over a woven-fabric background, as well as to fabric with skewness the problem of crossed-points detection becomes very difficult. To overcome this problem and to complete our automatic system for woven fabric recognition, the problem of crossed-points detection in fabrics with skewness or with non-periodic design and the problem of crossed-states detection will be investigated in future works.

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