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Applying Image Analysis to Automatic Inspection of Fabric Density for Woven Fabrics

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Abstract: The gray line-profile method is introduced to find fabric density. Some patterned fabrics like stripe design as well as solid fabrics of basic weave structures are used to verify the efficiency and accuracy of the method. The approach is compared with Fourier transform method. Although the gray line-profile method is concise, it shows good results in both solid and patterned fabrics. In addition, it does not require a pre-processing or filtering technique in space or frequency domain to enhance the image suitable for the analysis. However, the approach is slightly influenced by the filter size for finding the local minimums of profile graph.

Keywords: Image analysis, Fabric density, Fourier transform, Yarn spacing, Weave

Introduction

There have been some conventional methods to measure fabric density, i.e., the number of warp and weft yarns in a unit. Conventional means of measurement often require manual operations, which are time-consuming and readily make an operator's eyes tired. Thus, it is highly desirable to develop an automatic counting system for fabric density. Image processing has been proved to be an efficient method of analyzing fabric structures. The main methods so far are Fourier transform techniques [1,2]. The major principle here is to find the peak in the power spectrum, representing frequency terms of periodic elements from which the number of yarns can be recognized. However, it mostly requires the image of fabric to be filtered in space or frequency domain by an supervised method. Indeed, it is difficult to recognize the fabric density automatically using an unsupervised method from the power spectrum of the image [2]. Moreover, this approach is limited to the solid woven fabric as far as the input device like CCD camera does not cover entire color pattern. Even though the input device covers the entire pattern of a fabric, it hardly finds the fabric density because the periodicity of the pattern appears as combined power spectrum with that of other textures coming from fabric structure.

Other measuring methods use co-occurrence matrix and gray line-profile [3-5]. The co-occurrence matrix is based on a gray level of image and extracts texture measures from a fabric texture's image. This approach requires the fabric image to be pre-processed through histogram equalization [3] to reduce the gray level from 256 to 16 because of the complexity of co-occurrence operation. Compared to its complexity, the advantages are not much. The approach only shows good results for the plain fabric. The latter method, gray line-profile, was used by Kuo and Kim [4,5], where some image processing techniques like histogram equalization and morphology processes were pre-applied to enhance the image suitable for the analysis. Compared to other approaches, the strength and weakness of the line-profile method were not extensively studied by the previous researchers [4,5], who did not give attention to its characteristics. It might be due to the simplicity of the method.

In this paper, we are to investigate the efficiency, accuracy and the limit of the gray line-profile method and compare it with the Fourier transform technique.

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Experimental

Samples and Image Capture

Three basic weave structures - plain, twill and satin - are used in this study. Three samples of plain weave(solid and pattern), two samples of twill (solid and pattern) and one sample of solid satin weave were selected for evaluating the performance of the gray line-profile method. The characteristics of each fabric are shown in Table 1.

Images were captured by a scanner(Epson Stylus CX3100) with various resolutions and 0-255 gray levels. The resolutions used during capturing image are dependent on the fineness of the yarn in the fabric. The higher resolutions were required in the fabric of fine structure and the resolutions used for each sample are shown in Table 1.

Table 1. Characteristics of woven fabric samples

Sample code	Weave	Pattern	Density, yarns/inch (warp × weft)	Image resolution (dots/inch)
P1	plain	solid	53 × 52	600
P2	plain	stripe	40 × 35	300
P3	plain	hairline	67 × 61	600
T1	twill	solid	48 × 61	600
T2	twill	stripe	48 × 61	600
S1	satin	solid	80 × 48	600

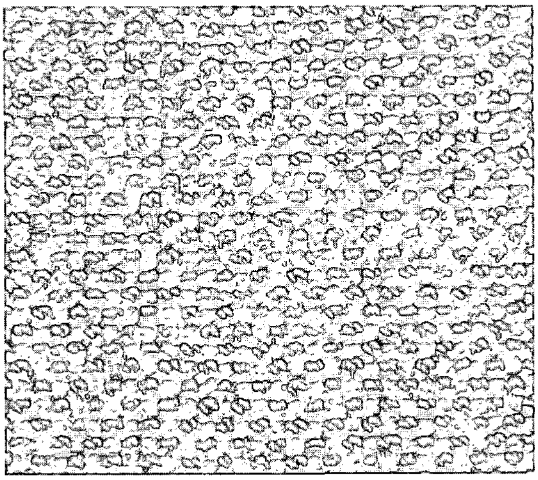

Figure 1. The image of plain fabric(P1) scanned at 600 dpi.

Figure 2. The binary image of plain fabric(P1) thresholded at intensity of 70.

Research Method

Figure 1 shows the captured image of plain fabric(P1), and the image in Figure 2 is binary format of P1 obtained by thresholding with the intensity of 70. As we see in the binary image, black marks appear along the boundaries between yarns. We use this property to find fabric density. These black marks are caused by the light transmitted through the fabric from the light source of the scanner. The boundary positions between yarns can be easily defined once the gray line-profile is obtained.

To get the gray line-profile, we assume the image size is m, n pixels in horizontal and vertical directions (namely, weft and warp directions respectively) as following

$$G_e(k) = \frac{\sum_{i=0}^{m-1} I(k, i)}{m}$$

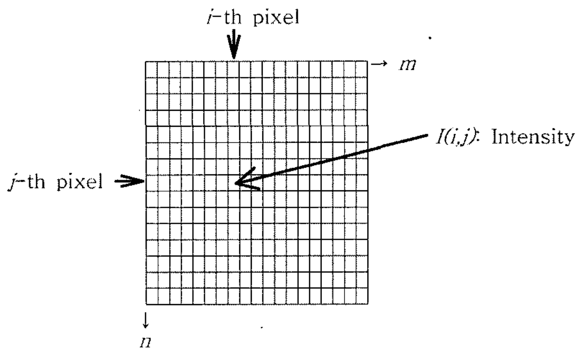

Figure 3. Digital expression of scanned image and its intensity.

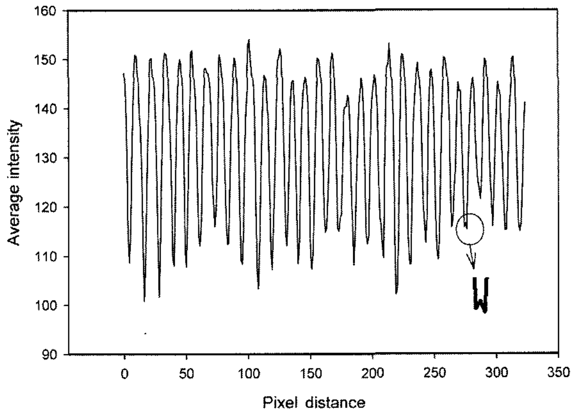

Figure 4. The gray line-profile of warp shows the change of intensity along weft direction.

Where $G_e(k)$ is average gray value of k-th horizontal line and $I(k, i)$ is the intensity of gray at coordinate (k, i).

$$G_a(k) = \frac{\sum_{j=0}^{n-1} I(j, k)}{n}$$

Where $G_a(k)$ is average gray value of k-th vertical line and $I(j, k)$ is the intensity of gray at coordinate (j, k).

Figure 4 shows the gray line-profile graph of sample P1 obtained with above equations. As shown, there are some valleys corresponding to the boundary position between yarns. Therefore, finding the local minimums in the profile graph is equivalent to define the boundaries between yarns. However, there are many local minimums on the profile graph. So, we developed an algorithm that checks a point whether it is local minimum or not among its n neighbors (so-called, filter size). If the point is smaller than the n neighbors then it is a local minimum, and if larger than n neighbors it becomes a local maximum. In this way we can find the valley points of the gray line-profile graphs.

Results and Discussion

We compared our results with that obtained from Fourier

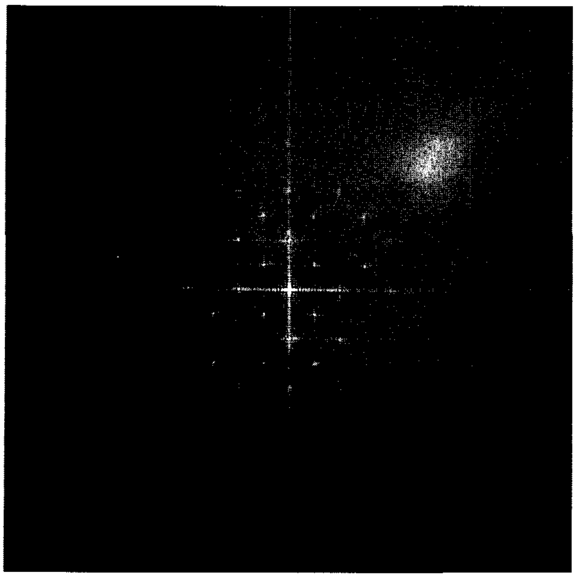

Figure 5. The power spectrum of plain fabric(P1).

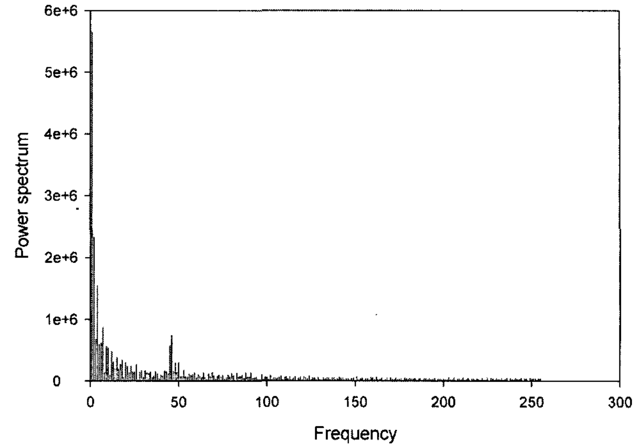

Figure 6. The power spectrum of plain weave(P1) in weft direction.

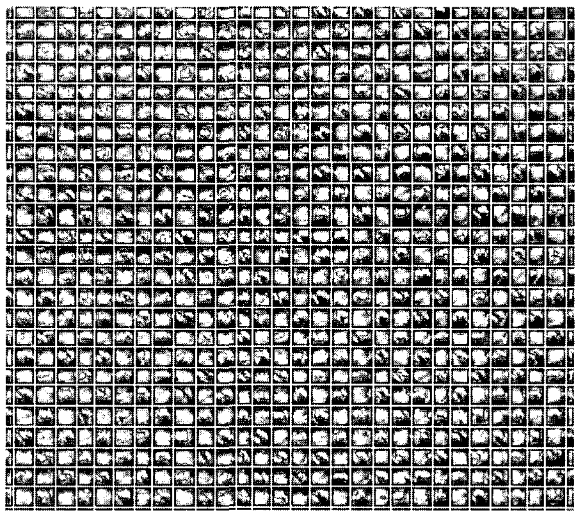

Figure 7. The line-profile result of plain fabric(P1) obtained with filter size $n = 2 \times 2$(warp × weft directions).

transform, which uses the periodic nature of fabric texture. The periodicity comes from the ridges formed by the weft and warp yarns which are arranged in two directions according to their weave construction. The Fourier transform converts the fabric image into a two dimensional complex function in a frequency domain. A power spectrum is derived from the Fourier transform, in which a periodic structure in the image will result in a peak (a high magnitude area). The value and location of power spectrum reveal the periodicity and directionality of the periodic structure. Figure 5 shows the power spectrum of the plain fabric(P1), which was normalized to express as an image. The normalization is usually performed to visualize the power spectrum, therefore making it easy to recognize the periodicity and directionality of the fabric texture.

The power at the origin (center of image) indicates the so-called direct component (DC), reflecting the average intensity of the image, and the power spectrum at other locations shows the different frequency terms present in the image. Namely, the next pixel to the right of the origin represents 1 cycle per image width. The next pixel to the right represents 2 cycles per image width and so forth. The further from the origin a pixel value is, the higher the spatial frequency it represents. Therefore if we could know which pixel in the spectrum image corresponds to warp repetition, warp density would be calculated based on the pixel position. So, we drew an graph of the power spectrum that contains the highest component next to the DC component in weft direction to know whether we can recognize the pixel. Figure 6 is the power spectrum graph and shows the highest peak at frequency 2, which means that a texture repeats twice per image width. Therefore, the frequency does not correspond to that of warp density. In this stage, we can not know what the frequency is because there are so many brightness changes on yarn and fabric due to yarn shape, fuzzy, weave and so on. Because of these, we can hardly judge which frequency corresponds to the periodicity of yarn itself. In case that a fabric has color pattern, the problem becomes more complicated. Xu [2] used a thresholding technique in frequency domain to extract the power spectrums corresponding to the yarn repetition. However the filtering technique looked ambiguous and was not described in detail. It might imply that the criteria for determining thresholding value was dependent on the fabric texture or something.

Figure 7 shows the result obtained from sample P1 with the gray line-profile after searching local minimum with filter size $n = 2 \times 2$(warp × weft directions). As shown in the figure, the calculated results correspond well with the ones human eye recognizes.

Figure 8 shows the image of stripe plain fabric(P2), woven with two warp yarns of different colors. Figure 9 shows the

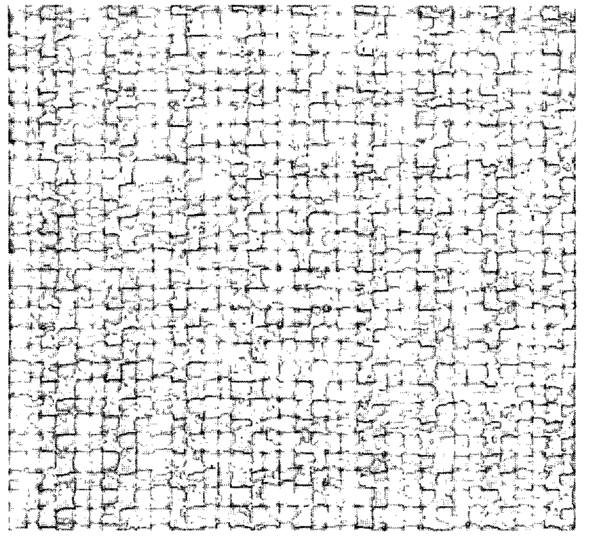

Figure 8. The image of stripe plain fabric(P2) scanned at 300 dpi.

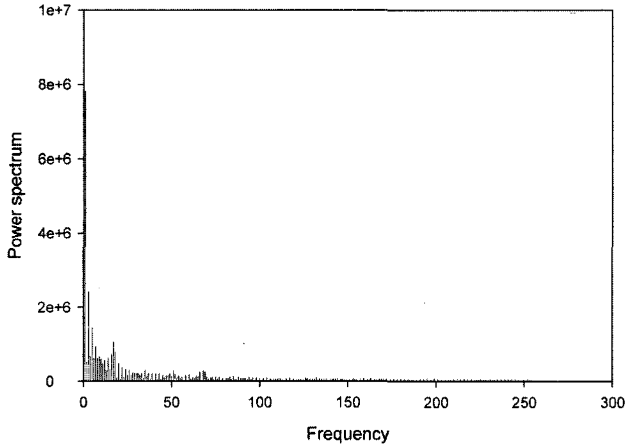

Figure 9. The power spectrum of stripe plain weave(P2) in weft direction.

power spectrum of the fabric(P2) in weft direction, which contains the highest power spectrum next to the DC component. As mentioned before, it is hardly possible to pluck out the frequency corresponding to the periodicity of warp yarn. So, we applied the gray line-profile method to the stripe plain fabric(P2) with filter size $n = 2 \times 2$(warp × weft directions) and obtained a result as shown in Figure 10. However the line profile method detected more the number of warp yarns than human eye recognizes. We tried it again with an increased filter size $n = 2 \times 4$, and got a reasonable result as shown in Figure 11.

The results tells that the fabric density obtained based on the line-profile can be influenced by the filter size, n. As mentioned in the previous part, n is the filter size used to find the local minima. Therefore we can conjecture that the filter size should not be bigger than the number of pixels corresponding to the width of yarn. This situation may cause

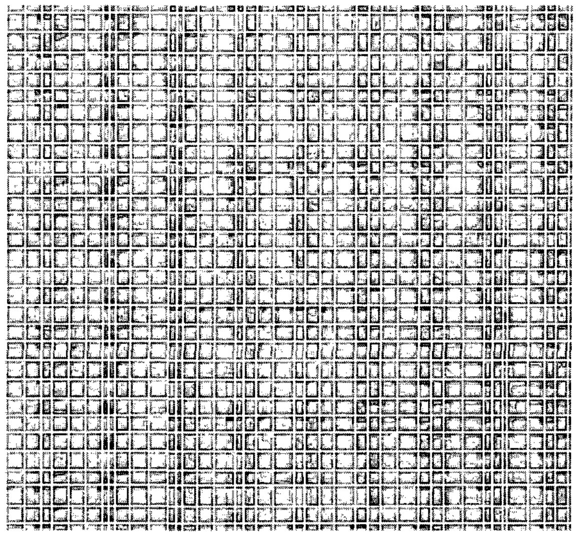

Figure 10. The line-profile result of plain stripe fabric(P2) obtained with filter size $n = 2 \times 2$.

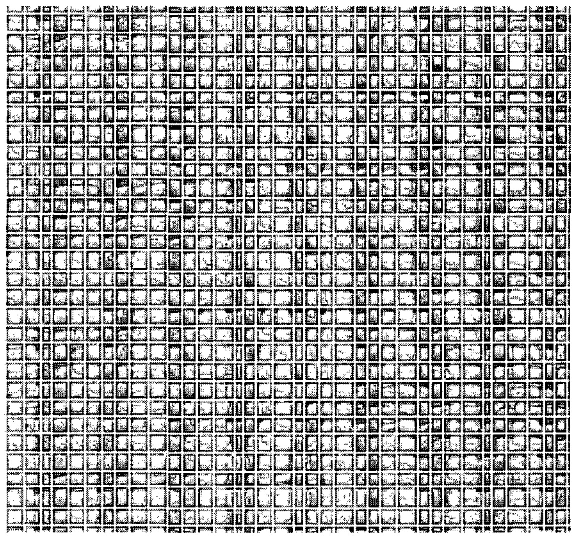

Figure 11. The line-profile result of plain stripe fabric(P2) obtained with filter size $n = 2 \times 4$.

a difficulty to determine a suitable filter size because the yarn width within a fabric is not constant and can not be predetermined. The filter size range for the fabric samples used in this study was from 2 to 6. For the stripe plain fabric(P2), 39 warp and 28 weft yarns were found in the image with the filter size $n = 2 \times 2$, and 36 warp and 28 weft yarns for $n = 2 \times 4$. Therefore caution should be given in selecting the filter size.

Also Figure 11 looks to insist that the line-profile method has an ability that Fourier transform does not. As we see, there are some deformed yarns on the figure due to jamming and flattening, causing its thickness to be irregular. Nevertheless, the line-profile method shows good results for the image.

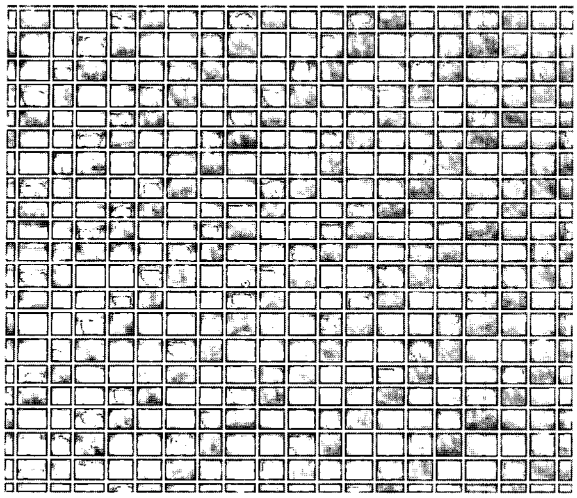

Figure 12. The line-profile result of twill fabric (T1) obtained with filter size $n = 2 \times 4$.

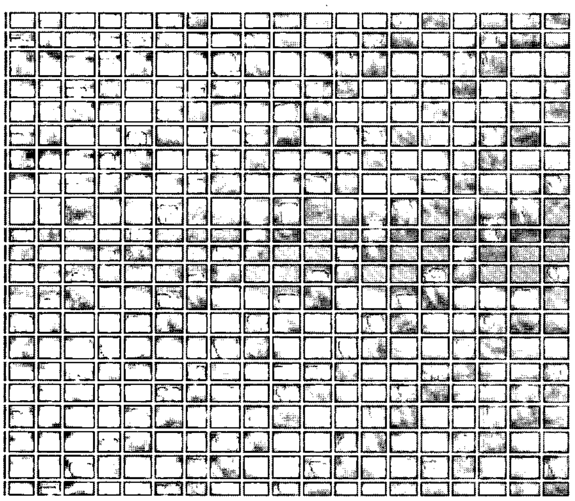

Figure 13. The line-profile result of stripe twill fabric (T2) obtained with filter size $n = 2 \times 4$.

This implies that the method is even valid to the fabric woven with various counts of yarns, which resulting in various thickness of yarns. However, there is another caution we have to pay, namely the warp direction should be parallel to the vertical direction.

Even though these two cautions are required, the line-profile method does not require the image to be pre-processed or filtered by some unsupervised methods. The most researches using image processing as a tool to analyze the fabric structure require certain pre-processing (or filtering in frequency domain), which is dependent on the status of the image. This causes some problems that we can not know what sort of filtering is good for the analysis in advance and generalized pre-processing does not exist.

With these little caution, we tried to find fabric densities for solid twill, stripe twill, and satin. Figure 12 and 13 show

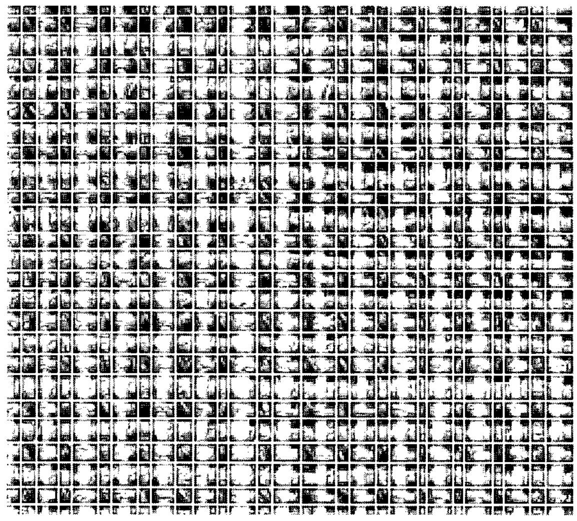

Figure 14. The line-profile result of two-tone plain fabric(P3) obtained with filter size $n = 2 \times 6$.

the results for twill weave, which corresponds well to the observation of human eye. In case of satin weave, the line-profile method did not work well because of characteristics of satin structure. Warp yarns in satin weave placed so closely contact each other, which made it difficult to recognize each warp yarn. It was also difficult to recognize the weft yarns because they were covered mostly by warp yarns. At very high resolution, even human eye could not count the number of warp yarns on the image. This result tells that the image analysis technique should be used under a circumstance where fabric texture appears well on the image.

We also applied the line-profile method to the blend fabric of wool and polyester, whose color looks like two-tone. Figure 14 shows the result of analysis. From these results, we can say that the gray line-profile is more reliable and conciser tool in finding fabric density than Fourier transform.

Conclusions

We investigated the performance of gray line-profile to find fabric density. We have discovered that the method gives us some benefits that can not be obtained from Fourier transform. Above all, the method does not require a pre-processing or filtering technique in space or frequency domain, which were mostly required in the previous researches and dependent on the approach methods and the input devices of image. We tried to find fabric density with Fourier transform, but we could not get a reasonable result for even a plain fabric without a filtering operation. On the contrary, the line-profile method presented good results for twill as well as plain weave. The method was also reliable for even the patterned fabric like stripe plain and twill and showed the possibility for the fabric woven with various counts of yarns.

The line-profile method showed a dependency upon the filter size for local minimum, however the results was not much sensitive and acceptable. Also, the gray line-profile method like other image analysis should be used under a circumstance where the fabric texture appears definite on the scanned image as much as human eye can recognize.

Acknowledgements

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