Image Processing Based Method Evaluating Fabric Structure Characteristics

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Abstract
A digital image processing approach was developed to evaluate fabric structure characteristics and to recognise the weave pattern utilising a Wiener filter. Images of six different groups were obtained and used for analysis. The groups included three different fabric structures with two different constructions for each. The approach developed decomposed the fabric image into two images, each of which included either warp or weft yarns. Yarn boundaries were outlined to evaluate the fabric surface characteristics and further used to identify the areas of interlaces to detect the fabric structure. The results showed success in evaluating the surface fabric characteristics and detecting the fabric structure for types of fabrics having the same colors of warp and weft yarns. The approach was also able to obtain a more accurate evaluation for yarn spacing and the rational fabric cover factor compared to the analytical techniques used to estimate these characteristics.

Key words: *fabric structure characteristics, pattern recognition, image processing, Wiener filter.*

Introduction

Visual analysis of a fabric sample is an essential process for reproducing this fabric and/or evaluating its structural characteristics. Basically this analysis defines the weave pattern, the densities of warp and weft yarns and probably the counts of warp and weft yarns by using a microscope. The process is traditionally carried out by a human inspector who uses a magnifier, ruler and some other simple tools to count the densities and visually define the weave pattern. Generally a manual operation like this is tedious, time-consuming and inconvenient for the inspector's eyes. Thus the judgment may not be consistent or accurate enough because it may vary from one inspector to another.

On the other hand, the dynamic development in computer speed and storage capacity opens the door for more advanced digital image analysis to replace the operations that depend on human vision. Using digital image analysis enabled detailed analysis of basic structural parameters of textile products [1]. It was used earlier to estimate the cross sectional area of wool fibres [2]. Thereafter other applications arose to estimate the irregularities of fibre blending on the yarn surface, to evaluate cotton maturity and to analyse the damage of wool fibres [3 - 7]. Other researchers utilised digital image analysis to characterise the basic structural parameters of a yarn's surface like the thickness, hairiness and twist [1, 8, 9]. Digital analysis was also used to characterise the texture of carpets during usage [10]. The term image processing appeared when techniques started to be more complicated and used some image processes to suit certain applications. An image processing technique was used to assess a fabric surface after pilling by analysing the brightness of each channel (Red, Green and Blue) of a coloured fabric image. Analytical techniques were used to assign the pilling grade for each sample based on counting the pilled area obtained from the image analysed [11]. Another image processing technique was used to measure the surface roughness of a knitted fabric. Fabric images were captured via a high resolution scanner and then analytical analysis was conducted in order to obtain the fabric roughness index [12]. Fabric wrinkle was also characterised utilizing image processing through analysing the heights of light profiles created by fabric wrinkle. Statistical parameters for the light profile were estimated to characterise the fabric wrinkle [13]. Frequency transforms were also utilised to estimate morphological features for nonwoven web [14] and to extract some image features to classify some knitted fabric defects [15]. Correction operations, like histogram leveling and autocorrelation erosion, were also used in other applications to classify some woven fabric defects [16]. A Wiener filter was used for weave pattern recognition by decomposing the fabric image into two images, one containing the warp yarns and the other weft yarns [17]. Then another image was initialised to define grid lines representing the central axis of yarns. The points where the central axis intersected were defined as the cross-over points. This technique assumed that the yarns are straight and identified the pattern by checking the intensity at each cross-over point. Depending on only one point and checking its intensity to decide which yarn is crossing over the other is not sufficient even if the yarns were straight.

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The aim of this work was to use image processing analysis to estimate some of the structural characteristics of woven fabric and to identify the weave pattern. The success of such an image processing approach will enable fast and accurate analysis of some of the fabric structure characteristics. The traditional procedure was known to be tedious, time-consuming and inconvenient for the inspector's eyes. All these drawbacks will be eliminated when the traditional procedure is replaced by a computer system that captures and processes fabric images. In this work, an image processing approach utilising a Wiener filter is presented to identify the pattern of woven fabric and estimate some of the fabric structure characteristics. Six groups of fabric samples were used in this work including three different fabric structures, namely plain weave, twill 3/1 and satin 5, with each structure containing two fabric constructions in order to have different structural characteristics. Five images were captured from each sample group to be analysed. The weave pattern, warp and weft densities and yarn diameters were identified and compared to sample data estimated using the traditional manual procedure.

Materials and image acquisition

Three fabric structures were chosen for this study and each fabric structure is represented by two fabric constructions. The three fabric structures are plain, twill 3/1 and five harness satin weave. All fabrics were manufactured from 100% cotton yarns. The six fabric samples were tested utilising the traditional manual procedure to identify the fabric structure and densities in both the warp and weft directions. The yarn counts of each sample were tested and the results agreed with those obtained from the fabric manufacturer. Detailed specifications of each sample are listed in ***Table 1***. The data represent the average measured values with their standard error and the data between brackets were provided by the manufacturer. All fabric samples were uni-color except sample number four, which was denim fabric with dark blue warp yarns and white weft yarns.

Table 1. *Specifications of fabric samples.*

ID	Fabric structure	Yarn density, thread per cm		Yarn count, tex	
		Warp	Weft	Warp	Weft
1	Plain 1/1	26 ± 0.409	35 ± 0.551	20 ± 1.194	28 ± 1.333
2	Plain 1/1	30 ± 0.495	26 ± 0.491	34 ± 1.637	34 ± 1.543
3	Twill 3/1	37 ± 0.562	20 ± 0.339	22 ± 1.301	16 ± 0.841
4	Twill 3/1	26 ± 0.542	31 ± 0.486	14 ± 0.778	20 ± 1.109
5	Satin 5	27 ± 0.530	18 ± 0.407	20 ± 1.261	14 ± 0.711
6	Satin 5	57 ± 0.746	29 ± 0.542	46 ± 1.977	42 ± 2.044

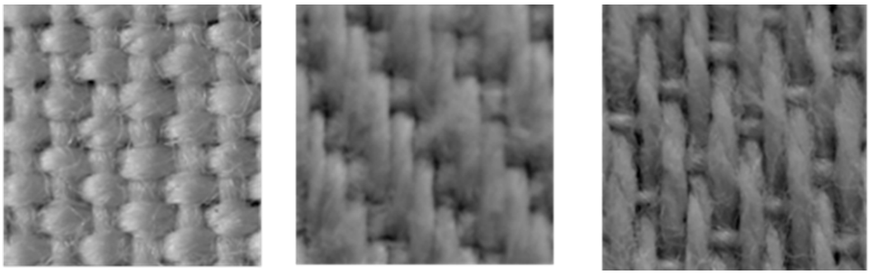


Figure 1. *Greyscale images for the three fabric structures; a) plain weave, b) twill weave, c) satin weave.*

A CCD camera equipped with a zoom lens attached was used to capture the fabric images under reflected light. Five different images were captured for each sample type, which were digitised using a frame grabber and transferred onto a personal computer to be stored. The image size was 512 × 512 pixels with a resolution of 6500 pixels per inch. All images were processed using histogram equalisation to reassign the brightness to improve the visual appearance. Coloured images were converted into two-dimensional greyscale images with 256 grey levels to improve the computer processing time and speed for the next image processing steps. Samples of images for the three structures are shown in ***Figure 1*** after the greyscale conversion.

Image processing approach

A Wiener filter was applied to the greyscale fabric images to regenerate two sub-images from the original image of the fabric. Each sub-image shows only one group of the two basic groups of yarns known as warp and weft. Generally the Wiener filter uses constant power spectra to reduce the noise within a local window of pixels. The Wiener filter calculates the value of each pixel using the following expression [17]:

$$W(m,n) = \mu + \frac{S^2 - v^2}{S^2}\left[I(m,n) - \mu\right]$$

where: $\mu = \frac{1}{MN}\sum I(m,n)$

$$S^2 = \frac{1}{MN}\sum I^2(m,n) - \mu^2$$

and v^2 is the variance of the noise.

The window's dimensions ($\boldsymbol{M}\times\boldsymbol{N}$) are chosen based on the application, and the filtration method depends on statistical calculations in the local neighborhood

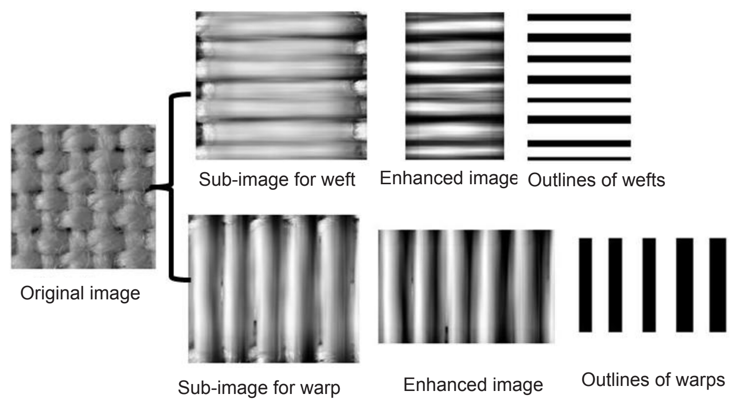


Figure 2. *Applying a Wiener filter on a plain weave image.*

of each pixel. Assuming that ***I*** represents the 2D matrix of the fabric's greyscale image and ***m***, ***n*** denote the indices of the image's pixel, hence ***I(m,n)*** will denote the intensity of the pixels in the grey level, which will vary from 0, black, to 255, white.

The shape of the texture in the warp or weft direction is always of the long line type. Therefore by applying the filter in the horizontal direction, the vertical texture is neutralised and vice versa. Choosing a window of short height and long width will produce a sub-image that contains only the weft yarn group. In this case the size of the window was chosen as 5×60 pixels. On the other hand, a window of long height and short width will produce a sub-image that contains only the warp yarn group. In this case the size of the window was chosen as 60×5 pixels. ***Figure 2*** shows a sample of the original greyscale plain weave fabric image under investigation and its sub-images resulting from applying a Wiener filter. Histogram equalisation and adjustment processes are applied to the resulting images in order to enhance the quality of the images, as shown in ***Figure 2*** (see page 87).

Some noises are recognised at the top and bottom in the sub-images that contain the warp yarn group and also on the sides in the sub-images that contain the weft yarns group. Removing these parts will ease the process of detecting the outbound of yarns and will not affect the further processes. The resulting sub-images are enhanced again utilising histogram equalisation and converted into binary images. Clustering thresholding or Otsu's method is used to obtain the threshold values of fabric images in order to convert them into binary images [18]. Otsu's method is considered as one of the most referenced methods. This method establishes an optimum threshold by minimising the weighted sum of within class variances for the foreground and background pixels. The minimisation of within class variances is equivalent to the maximization of between class scatter. The method's results are considered satisfactory when the numbers of pixels in each class are close to each other. Small holes (3×3 pixels) and short-thin lines showing up in binary images are considered as noise and removed. Then the outbound of each yarn in both directions is outlined, as shown in ***Figure 2***.

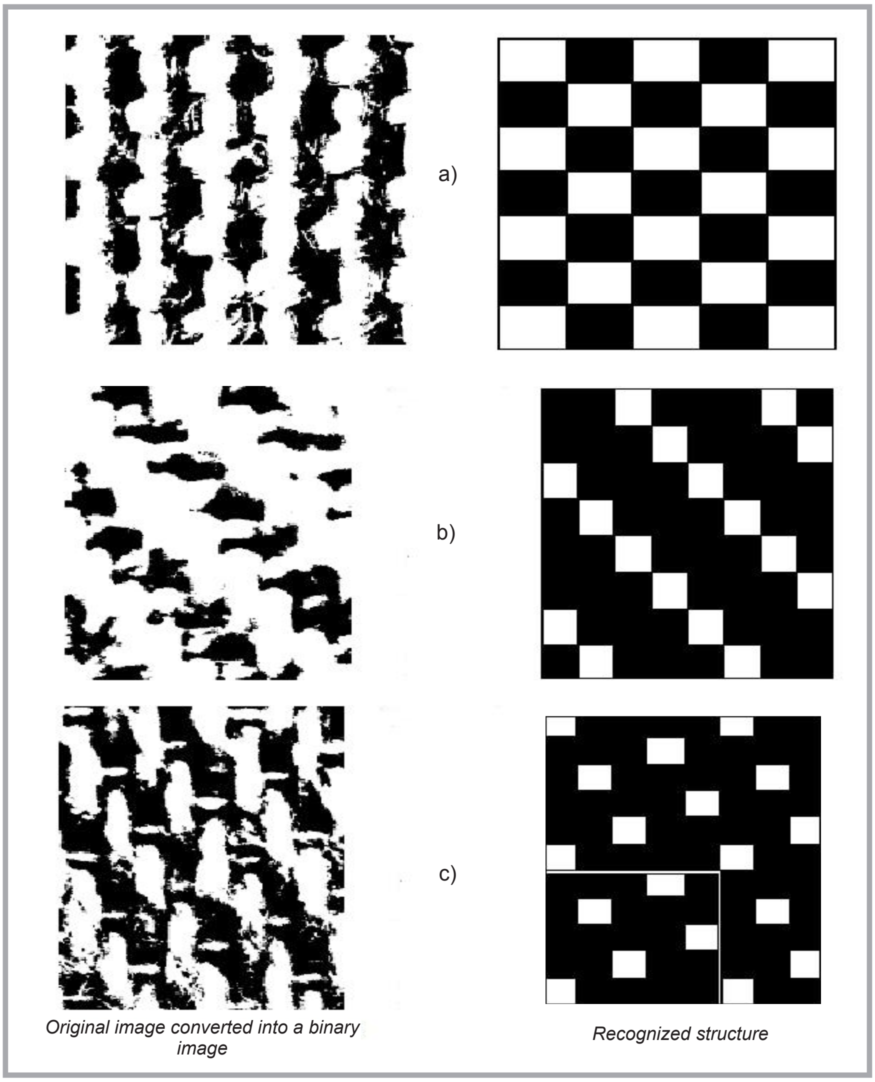


Figure 3. *Original image converted into a binary image and the structure identified; a) plain weave, b) twill weave and c) satin weave.*

Densities and yarn count calculations

The outlines of yarns shown in the last step of ***Figure 2*** are further used to calculate the mean value of the yarn diameter in each direction by relating the image resolution to the number of pixels representing each yarn width. The mean diameter of warp and weft yarns calculated can be used to calculate the English yarn count (N_e) using the following relation:

$$d \approx \frac{1}{28\sqrt{N_e}}$$

Also the number of yarns in each direction is identified and used to calculate the density in each direction using the information of the image dimensions. The same technique is used to calculate the yarn spacing.

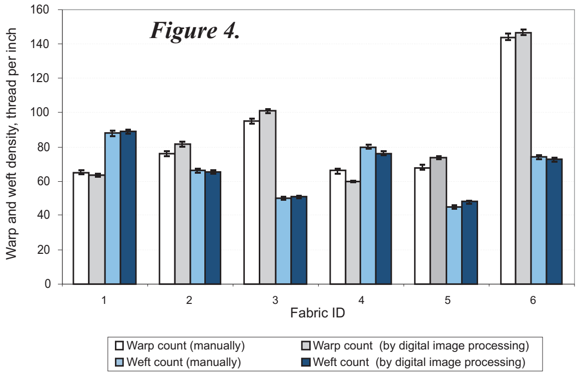
Fabric cover factor

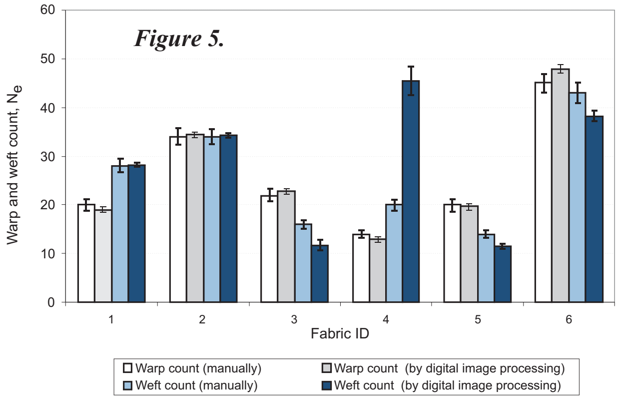
In general, the cover factor indicates the extent to which the area of a fabric is covered by one group of yarns, *i.e.* for any fabric there are two cover factors: one for the warp yarns and the other for the weft. Pierce presented the following equation to calculate the cover factor for each group [19]:

$$Cover\ factor = \frac{n}{\sqrt{N_e}}$$

Where n is the number of threads in one inch and N_e is the English yarn count.

The fractional cover factor is also known to represent both groups of yarns, defined as the total area of the fabric covered by the component yarns. A simplified approach is used to calculate the fractional cover factor, assuming that the yarns have a circular cross-section. If the yarn diameter is d and the adjacent yarn is displaced by a distance s, the fractional cover factor is expressed as d/s. In an ideal model, $\boldsymbol{s}$ is equivalent to $1/n$, and hence the fractional cover will be $d \times n$. If C_w is the fraction cover for the warp and C_f





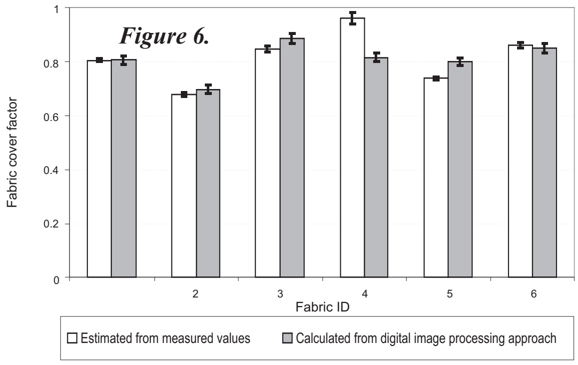


Figure 4. *Comparison between the densities measured and density results of approach presented.*

Figure 5. *Comparison between the counts measured and count results of approach presented.*

Figure 6. *Comparison of fabric cover factor results.*

is that for the weft, the total fabric cover factor will be: $C_w + C_f - C_w C_f$.

Pattern recognition

The outbound of yarns in each sub-image is identified as mentioned previously for each fabric image, as shown in ***Figure 2***. Only the outlines of yarns are captured in each sub-image to produce another two images containing only the lines representing the yarns' outlines, and by adding up these two images an image results containing grid lines. At this point, the windows representing yarn cross-over areas are identified. Applying this information on the original fabric image after converting it into a binary image utilising Otsu's method, the windows representing cross-over areas are defined in the binary image. Then the intensities of all the pixels within the window are summed. The analysis shows that areas where weft yarn crosses over warp yarn are much brighter compared to those where warp crosses over weft. To this end, the fabric structures are identified as shown in ***Figure 3***, where white marks mean that weft yarn is crossing over warp yarn. This approach evaluates the weave pattern based on the intensity in each cross-over area, which makes it more reliable and able to detect a wide range of weave patterns.

Results and discussion

The image processing approach was applied to various fabric images to calculate some yarn parameters and to identify the weave pattern. The image processing approach was applied for all images and the pattern recognition results were compared to the known weave patterns. The approach presented was able to identify successfully the pattern of the fabric structure for all samples except for sample number 4 (denim fabric). The main problem with that sample was the colour difference between the warp and weft yarns. The colour of warp yarns was dark blue (too dark) and that of the weft yarns was white (too bright). All enhancement processes failed to decompose the yarns accurately. Because of the colour difference, some yarns were merged together and some were split. Thus the image processing technique was not able to recognise the yarn boundaries and hence neither the cross-over areas for that sample. ***Figures 4*** and ***5*** show the approach results for densities and yarn counts compared to the values measured via the traditional procedure. Results showed good agreement between the two procedures. Some differences between the counts resulting from the approach and counts measured are identified for twill and satin weave, the reason for which is based on the concept of obtaining the count from the image approach. The image approach calculates the width of the yarn's projection, not the yarn diameter, and uses this information to calculate the yarn's count. Comparing the approach results to the results measured, one can notice that there is a significant difference in the weft counts compared to the warp counts for both twill and satin weave. Weft yarns have less tension compared to warp yarns during the weaving process, and this gives the possibility of weft yarns becoming flattened, especially when they have the space, which is provided in fabrics with low yarn densities and/or in fabric structures which have a relatively long float length, like twill and satin weave. This clarifies why there is almost no difference between weft counts for plain weave; however, differences start appearing in twill and satin weaves.

The results listed in ***Table 3*** (see page 90) show the yarn spacing calculated by the digital image processing approach. ***Figure 6*** shows the results of the image processing approach for the fabric cover factor compared to the values estimated, calculated from the data measured, i.e. fabric density and yarn counts. It is noticed that there is not much difference between both results (excluding

Table 2. Mean yarn diameter and spacing calculated using the digital image processing approach.

ID	Mean yarn diameter, mm		Mean calculated yarn spacing, mm	
	Warp	Weft	Warp	Weft
1	0.208	0.170	0.373	0.356
2	0.155	0.155	0.432	0.406
3	0.191	0.239	0.254	0.533
4	0.254	0.191	0.406	0.432
5	0.206	0.241	0.457	0.559
6	0.132	0.147	0.178	0.432

results of sample no. 4). In our opinion, the image processing results of the fabric density, the projection of yarn diameter, yarn spacing and the fabric cover factor tend to be more accurate because of considering the yarn projection in the fabric. However, some variations appear in the yarn count results for the fabric structures that have a long float due to the yarn flattening, which changes the projected yarn diameter. Therefore it can be concluded that the image processing technique is able to analyse fabrics that have warp and weft yarns with the same color or uni-color fabrics. The image processing approach was able to assign the densities of warp and weft yarns, the yarn spacing, diameters of warp and weft yarns and counts of warp and weft yarns. In addition, the approach developed successfully identified the different weave patterns. It can be predicted that the approach developed will be able to identify a wide range of patterns once it can identifythe yarn boundaries and, hence, the cross-over areas.

Conclusions

This work focused on identifying the pattern of a woven structure in addition to evaluating other surface characteristics utilising the digital image processing approach. The approach developed uses a Wiener filter to decompose the fabric image into two sub-images, each of which containing either a warp yarn group or weft yarn group. The sub-images are further analysed to outline the yarn boundaries and hence characterise fabric surface characteristics. Yarn diameter, yarn spacing, yarn count, densities in both directions and the rational fabric cover factor are characterised. Yarn boundaries are further used to identify the areas of interlace or the cross-over areas, which are processed to identify the fabric structure. Six fabric samples were used in this study to evaluate the approach developed. The samples included three fabric structures with two constructions for each structure. The samples were analysed manually using a magnifier and the results were compared to those of the approach developed. The approach results showed good agreement compared to the results pre-identified for the samples having the same colour for both warp and weft yarns. On the other hand, the approach developed failed to analyse the sample that had an extreme difference in the colours of warp and weft yarns. The approach was not able to identify the yarn boundaries of this sample and hence neither the fabric surface characteristics. The large variation in the colours of warp and weft yarn in this sample confused the image processing approach and gave false results by merging two adjacent yarns or splitting one yarn into two. The approach developed also gives us a better understanding of how the weaving process could alter some yarn dimensions, thus giving more accurate results for yarn spacing and the rational fabric cover factor.

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