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Objective Measurement of Water Repellency of Fabric Using Image Analysis (I) – Methodology of Image Processing –

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Abstract: A methodology for the objective evaluation of water repellency is studied using image analysis of the sprayed pattern on woven fabrics according to a standard spray test (AATCC Test Method 22-2001). The wet area ratio obtained from the spray standard test ranking is found to be exponentially related with its water repellency rating. Mean filtering is used to remove the effect of weave texture and the transmitted light through interyarn spaces. The ring frame of the instrument and wet region are recognized using Otsu thresholding technique. And Hough transform and outline operation are used to obtain the size and position of the ring frame. The objective assessment of the water repellency using image processing can reduce unnecessary confusion in the subjective determination of the water repellency.

Keywords: Water repellency, Image analysis, Otsu thresholding, Hough transform, Image processing

Introduction

There has been considerable interest, among both researchers and technologist working in the textile and apparel manufacturing industries, on the application and implementation of fabric objective measurement technology throughout the past decade [1]. Recently, advanced computer technology has promoted the introduction of objective measurement in various fields, such as fabric handle, drape, pilling, wrinkle and so forth [2]. The objective measurements originated from the inconsistency and inaccuracy of the subjective assessments which are frequently influenced by the mental and physical conditions of an inspector. The drawbacks of the subjective measurements can be minimized by introducing image analysis technique, which has been widely used for characterizing and inspecting general textiles including textured materials [2].

Water repellent fabrics are used in the application fields of clothing, household, technical textile including sportswear, carpets, work wear, awnings, curtaining fabrics, cotton upholstery, automotive fabrics, and bed/table linen, etc. The term 'water repellent' describes a state characterized by the non-spreading of a globule of water on a textile material and it is not normally applied to a water-repellent finish impervious to air which is generally referred to 'water proof' [3]. High level of water repellency can be obtained either by the use of a thoroughly prepared fabric surface of fine yarns and close-packed textile structure or by uniform application of a chemical finish to produce a surface with a lower critical surface tension than the surface tension of water (ca. 73 mN/m) [4,5]. Tightly woven synthetic fabrics based on micro-filaments of 1.0 dtex or less can serve as an excellent base fabric for water repellency due to decreased interyarn capillary spaces. Singeing treatment after desizing and scouring are usually required to remove protruding surface fiber as well as impurities which may decrease the performance of water-repellent treatment by causing non-uniform film formation and facile wetting and wicking of water into the fabric structure.

One of the most widely used test methods for water repellency is a spray test which simulates exposure to rain: AATCC Test Method 22: 2001 (Water-Repellency: Spray Test) is technically equivalent to ISO 4292 and KS-K 0590: 2001 (Testing Method for Resistance to Surface Wetting: Spray Method) [5,6]. A preconditioned and taut test specimen is sprayed through a standard nozzle with a fixed amount of water, which produces a wetted pattern whose size depends on the relative water repellency of the fabric. And the wetted and tapped pattern is evaluated by visually comparing with pictures on a standard ranking chart. Although the method is rapid and simple, the evaluation is carried out by subjective determination of the patterns based on six photographic pictures representing each rating scale, which may cause inevitable discrepancy between individual observers due to the different physical and mental states of the observer at the time of determination. In addition the intermediate wetted pattern of the specimen between successive standard rating may make the observer difficult to give correct and confident evaluation. Therefore, we are to develop an algorithm to evaluate water repellency objectively with image processing.

Experimental

To evaluate the water repellency of a fabric, we use the AATCC Test Method 22-2001 standard, which grades a wetted pattern into 6 ranking by comparing with the standard photographs. The wetted pattern of a fabric is scanned at 150 dpi (dots per inch) using image scanner (EPSON CX3100). The sample images are composed of a matrix of pixels with 8-bit gray levels and used in evaluating the water repellency. The algorithm for evaluating water repellency is implemented with Java and tested with the fabrics as specified in Table 1.

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Table 1. Properties of fabrics

Weave code	Plain				2/1 Twill		3/1 Twill	
	P1		P2		T1		T2	
Ends/cm, picks/cm	35	21.8	35	31	37.8	23.6	28.4	27.2
Yarn count (tex)	13	13	16.5	14	29.5	29.5	19	19
Cover factor (CF-F*)	0.64		0.75		0.90		0.72	

*The cover factor and CF-F were defined by using the method given by Grosberg [7]: $CF-1(warp) = 3.86\times10^{-3}\times(\text{ends/cm})\sqrt{tex}$, $CF-2(weft)$ $3.86\times10^{-3}\times(\pi cks/\text{cm})\sqrt{tex}$, $CF-F(area) = CF-1+CF-(CF-1\times CF-2)$.

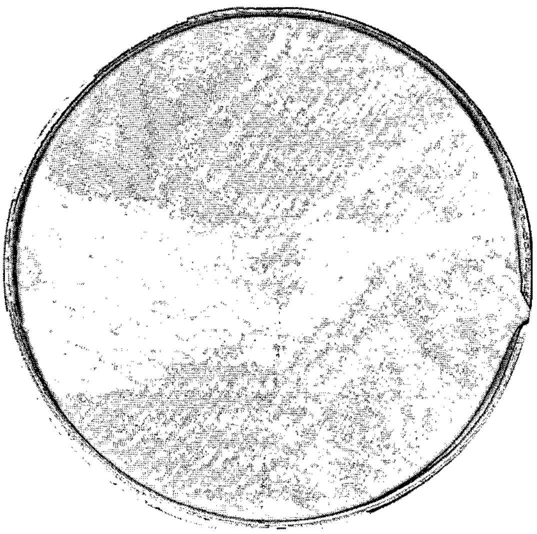

Figure 1. The sprayed and scanned image of a tested sample(T1) according to the AATCC Test Method 22-2001.

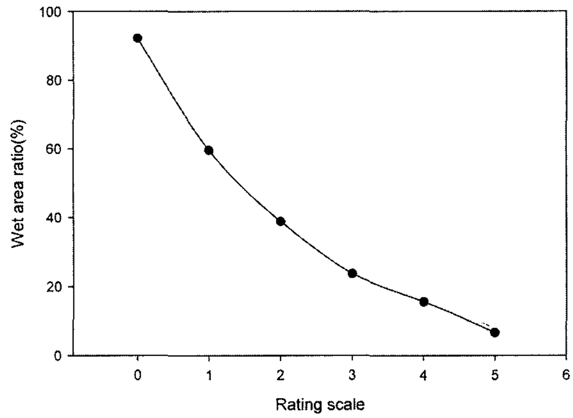

Figure 2. The relation between wet area ratio and rating scale obtained from standard method (AATCC Test Method 22-2001).

Feature of Water Repellency Measurement

In grading a fabric for water repellency, it is important to know what feature is critical among several characteristics. For example, in pilling test, lots of feature values were developed to describe and evaluate the level of pilling [8,9]. Hsi *et al.* [8,9] studied on this subject extensively and calculated pill dispersion index, number of pills, mean size, shape factor, contrast, and orientation of pills. The author concluded that the number of pills was mostly related to the visual estimation of human. In water repellency, visual assesment of water repellency seems more apparent than the pilling evaluation as seen in Figure 1 which is the image of sample fabric (T1) after testing.

The level of water repellency seems to depend closely on the wet area of a test fabric. To prove the hypothesis, the wet area ratios of the standard ranking photographs of AATCC Test Method were calculated. Figure 2 shows the relationship between wet area ratio and the level of water repellency obtained from the standard method. The figure indicates that the wet area ratio has close relationship with rating scale even though it is not linear but exponential. This could be a cause of inaccuracy and inconsistency of the subjective visual determination by human. Therefore, we are to develop an algorithm to measure wet area on the textured material objectively as follows.

Methodology

Thresholding

The image of wet fabric taken by the scanner is formated to an 8-bit bitmap whose gray scales are from 0 (black) to 255 (white). In the image, the wet region has different gray scale from dry region as seen in Figure 1. And the pixel values within the wet region are not uniform because of the texture of fabric weave and the light transmitted through interyarn spaces. To ensure reliable measurement, the pixels in wet region must be identified reasonably and consistently regardless of the image status.

Thresholding is one of the simplest and most commonly used techniques to separate the foreground (object) of an image from its background by turning all pixels below some threshold (T) to zero and all pixels above that threshold to one. The major issue in the thresholding technique is how to determine threshold T. Figure 3 illustrates the traditional global thresholding approach to separate a grey scale image into two subimages, foreground and background, using the intensity histogram of the image. The foreground-background separation point is defined by a threshold value T, which is selected using some criteria to best separate the two subimages.

We thresholded the image of Figure 1 with a threshold

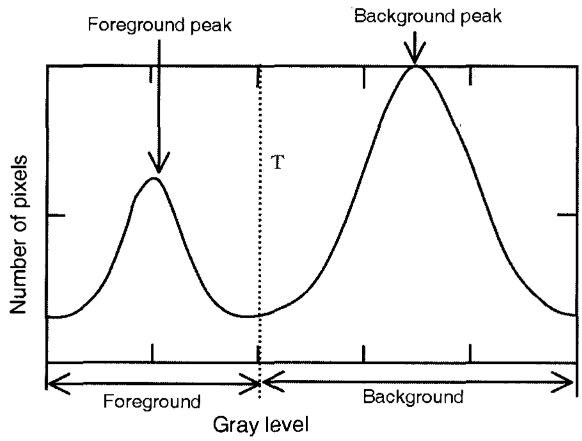

Figure 3. Global thresholding using intensity histogram.

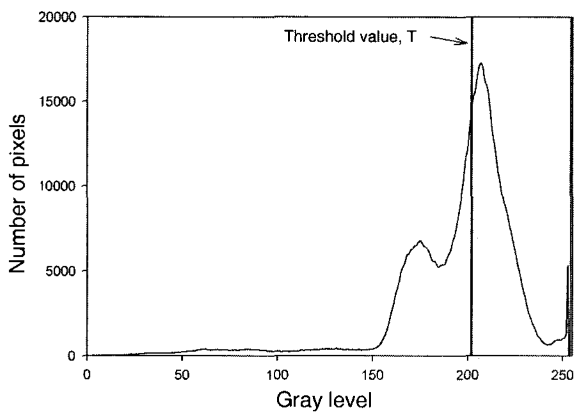

Figure 4. The histogram of wet fabric and its thresholding value determined by human's trial and error.

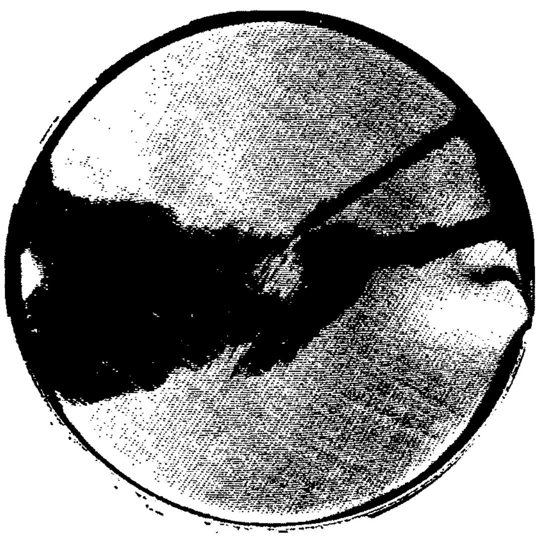

Figure 5. The binary image of wet sample after thresholding with a criteria determined by human's trial and error.

value determined by human's trial and error based on its histogram of Figure 4. In the result of thresholding as given in Figure 5, the wet area and background are not separated well because there exist common intensity values on both sides of foreground and background, which is mostly caused by the transmitted light through interyarn spaces. To relieve the problem, we apply mean operation to the wet image before thresholding. The mean filtering replaces each pixel value in the wet image with the mean ('averag') value of its neighbours including itself which eliminate unrepresentative pixel values of their surroundings. Therefore, the unexpected intensities due to the transmitted light are neutralized by its neighborhood pixels whose size is the measure of the filtering effect. In this study, two sizes of the kernel 3 × 3 and 5 × 5 are tried.

To threshold the image automatically not by human's trial and error approach, Otsu's thresholding theory is adopted [10]. Otsu's method determines the threshold by minimizing the within-class variance of the two groups of pixels separated by the thresholding operator. The method assumes that an image has N gray levels and its normalized histogram (i.e., for each gray-level value i, $p(i)$ is the normalized frequency of i). If n_i is the number of pixels at gray level i, then $p(i)$ is defined as $p(i) = n_i / \sum_{i=0}^{N-1} n_i$. With this, we can define the within-class variance as the weighted sum of the variances of each cluster:

$$\sigma^2_{within}(T) = \omega_B(T)\sigma^2_B(T) + \omega_o(T)\sigma^2_o(T) \tag{1}$$

where,

$$\omega_o(T) = \sum_{i=0}^{T-1} p(i)$$

$$\omega_B(T) = \sum_{i=T}^{N-1} p(i)$$

$\sigma^2_B(T)$: the variance of the pixels in the background (below threshold)

$\sigma^2_o(T)$: the variance of the pixels in the foreground (above threshold)

Computing the within-class variance for each of the two classes for each possible threshold involves a lot of computation. However the computation can be reduced by subtracting the within-class variance from the total variance of the combined distribution. Following equation is the result, so called the between-class variance:

$$\sigma^2_{between}(T) = \sigma^2 - \sigma^2_{within}(T) = \omega_B(T)[\mu_B(T) - \mu]^2 + \omega_o(T)[\mu_o(T) - \mu]^2 \tag{2}$$

where σ^2 is the combined variance and μ is the combined mean.

The. above equation indicates that the between-class variance is simply the weighted variance of the cluster means themselves around the overall mean. If we substitute $\mu = \omega_B(T)\mu_B(T) + \omega_o(T)\mu_o(T)$ and simplify the equation, we get

$$\sigma^2_{between}(T) = \omega_B(T)\omega_o(T)[\mu_B(T)-\mu_o(T)]^2 \qquad (3)$$

A program was implemented to find a thresholding value T minimizing the between-class variance ($\sigma^2_{between}$). Before the thresholding value calculated, a mean filtering is applied first to remove the effect of the transmitted light. Figure 6 is the result image thresholded according the logic we mentioned, where the ring frame is separated from background instead of the wet region of fabric. It assures that the Otsu technique works well according to its principle.

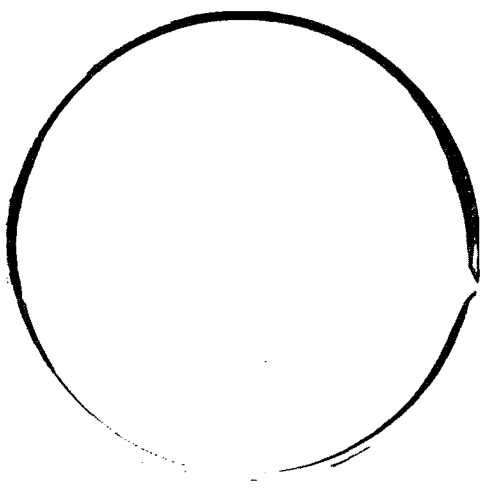

Figure 6. The image after applying Otsu thresholding over the entire wet image.

The size and center coordinate of the ring must be found because they are required to calculate the inside area of the ring frame. They are also needed for the separation of the wet region from the background because the thresholding operation should be limited within the ring frame.

Recognition of the Ring Frame

To determine the size and position of the ring frame, Hough transform is adopted, which does not require continuous path of edge pixels, nearby edge pixels. The method was introduced by Hough [11] and determines parameters by a voting scheme. The basic principle of the approach is to switch the roles of parameters and spatial variables. For example, we assume to detect points that lie on a circle of known radius, r. *A* circle can be defined by following equation with x, y the spatial variables and u, v the parameters (center) of the circle in the spatial domain.

$$(x-u)^2-(y-v)^2-r^2 = 0 \qquad (4)$$

Now, the parameter space is assumed, which represented by the coordinate system u, v. A point x_i, y_i in the spatial domain corresponds to a circle in the parameter space centered at x_i, y_i. For every point in the spatial domain, there exists a circle in the parameter space, and vise versa. The intersection of circles in the parameter space identifies centers of circles in the spatial domain. The number of intersecting circles in the parameter space is directly related to the number of points that lie on this circle (Figure 7). The Hough method is usually implemented by an accumulator array, which is an n dimensional, discrete space, where n is equal to the number of parameters. In our case with circles of known radii, the parameter space is two-dimensional. Each circle is discretely

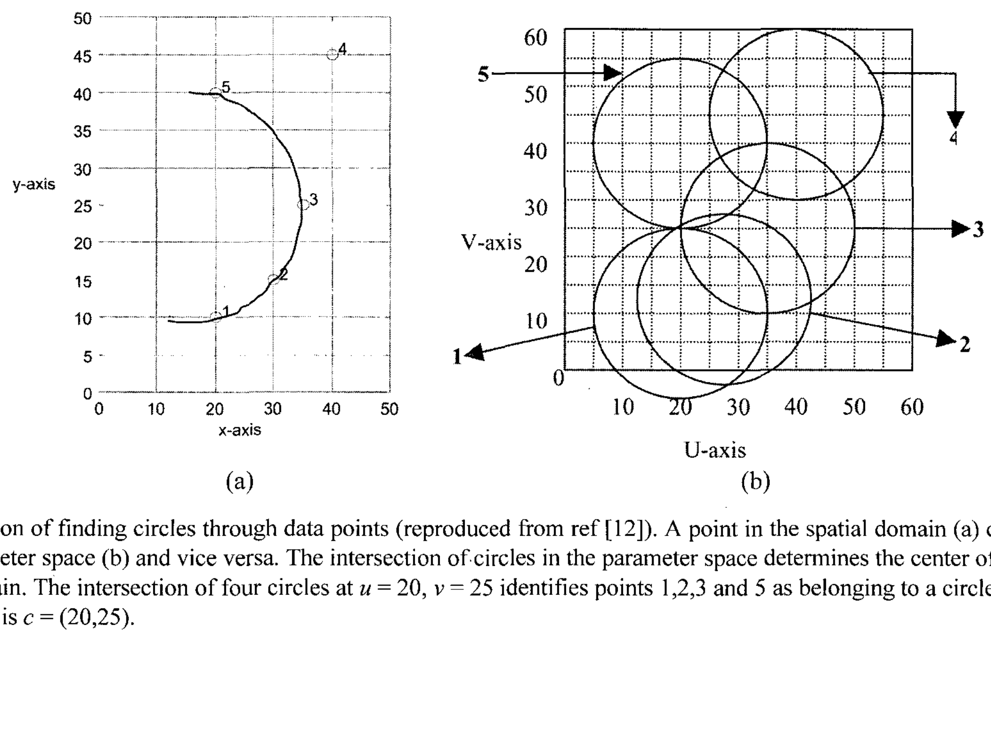

Figure 7. Illustration of finding circles through data points (reproduced from ref [12]). A point in the spatial domain (a) corresponds with a circle in the parameter space (b) and vice versa. The intersection of circles in the parameter space determines the center of the sought circles in the spatial domain. The intersection of four circles at $u = 20$, $v = 25$ identifies points 1,2,3 and 5 as belonging to a circle whose center c in the spatial domain is $c = (20,25)$.

represented in the parameter space. To keep track of all the circles, we simply increment all of the cells that are turned on by every circle. After all points are processed in this fashion, the accumulator array is analyzed and the number of hits per cell is determined. Since every hit casts one vote for a point lying on that particular circle, the cell with the maximum number of hits, m, yields the center of the circle in the spatial domain that passes through m points.

Although the Hough transform is an effective technique for detecting and finding circle images within noise, it requires high cost for the memory and calculation time. In this study, the cost is reduced by applying the Hough transform only to the outline of the thresholded image of Figure 6. To get an outline of the image, an erosion operation

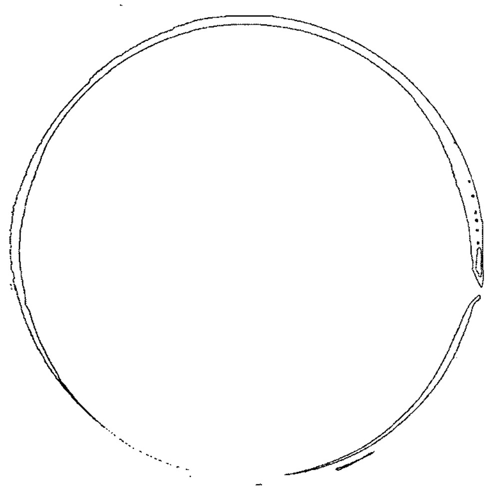

Figure 8. The outline of ring frame obtained by applying erosion and subtraction operation.

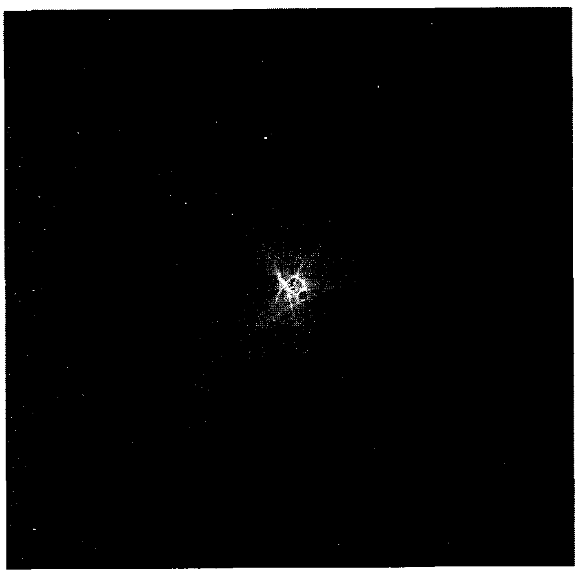

Figure 9. The visualized accumulator array for a given radius where the brightest pixel represents the center of the ring.

is applied to the image which shrinks an object by one pixel around their perimeters [13]. Then, the eroded image is subtracted from the original image. Figure 8 shows the result of outlining operation. Since the size of the ring frame is known, the range of radius of the inner circle in Figure 8 can be restricted in calculating Hough transform. Figure 9 shows the visualized image of accumulator array obtained from Hough transform, where the brightest point represents the center of the ring frame.

Recognition of Wet Region

Until now, the region and its position of the ring frame have been successfully defined using Otsu thresholding technique and Hough transform. The last step is to separate the wet region from the background. Otsu thresholding is used once more, however the resultant region is different from the previous one because the operation is restricted to the inside of ring frame whose size and position were already determined before. After the thresholding, median filtering is used to remove scattered noises and a binary operation of closing to fill tiny holes caused by the gaps between yarns or texture of fabric weave [13]. Figure 10 shows the final result of Otsu thresholding. It is interesting that the thresholding gives different results according to the range of region where Otsu thresholding is applied. It is the strong benefit of Otsu thresholding technique that classifies the object and background automatically by minimizing the within-class variance of the two groups of pixels.

Results and Discussion

We have applied several image processing techniques to separate wet region from background. Figure 11 shows the scheme of the image processing we have followed to evaluate water repellency. The developed algorithm was tested with

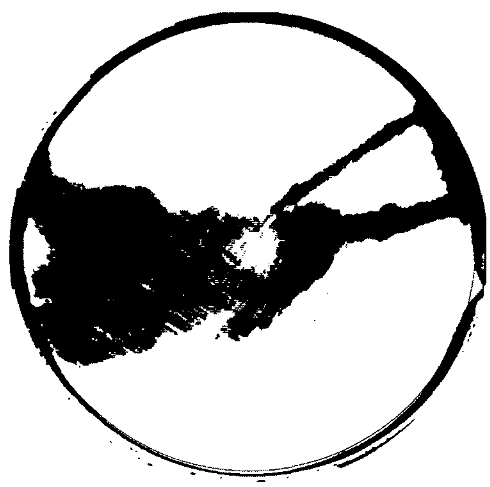

Figure 10. The result of water repellency test after applying Otsu thresholding within the ring.

solid fabrics of different weaves and cover factors. The algorithm is not influenced by the texture of fabric weave, but by the contrast between wet region and background and the amount of transmitted light through inter-yarn spaces. The transmitted light appears as black marks on the fabric surface that exist on both sides of wet and dry regions, therefore it makes to difficult to separate the wet region from background using a thresholding technique. We can conjecture that the amount of transmitted light is related to the cover factor or compactness of a fabric. Therefore the mean filtering need to be adjusted for a fabric of low compactness, which shows more black noises on the image. Fortunately, the situation was easily controlled in this study by increasing the kernel size of mean filtering from 3 × 3 to 5 × 5. For the images of low contrast which often occurs in the white sample fabric, histogram equalization [13] was applied to the fabric before applying mean filtering. Histogram equalization is known to be effective image processing technique in enhancing the contrast and it was not needed in most fabric samples except extremely white sample.

With the image processing techniques, the wet area ratios were measured for the fabrics listed in Table 1. Then, the wet area ratios were compared with the values obtained by manual measurements, which was done by weighting the sample fabric and wet area after testing. Table 2 shows the wet area

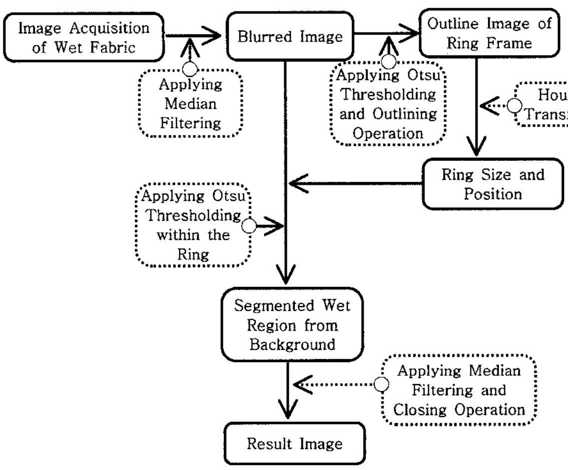

Figure 11. Flow diagram of water repellency evaluation.

Table 2. Comparison of wet area ratio between manual and image processing method*

Fabric	Wet area ratio (%)	
	Manual method	Image processing method
P1	70.67	69.61
P2	9.70	9.31
T1	43.80	42.87
T2	28.73	28.87

*Paired t-test value is 0.13.

ratios and statistical result which indicates that there is good agreement between both methods (a paired t-test gave a value of 0.13).

Conclusions

We have investigated the algorithm for evaluating water repellency of woven fabric. The standard photographs of AATCC test method is used to relate its grade with the wet area ratio. This study shows that the grade of water repellency is exponentially related with the wet area ratio, substantiating that the objective measurement of water repellency is meaningful. To calculate the wet area ratio of a fabric, it is essential to separate a wet region from the background of a fabric. However, it is not easy because of the texture of fabric weave and the transmitted light through interyarn spaces that makes black spots appeared on the both sides of wet and dry regions. The problem is relieved by applying mean filtering to the image, and the bigger kernel size of the filter for the fabrics of low compactness. Our study shows that thresholding technique is very important in separating the wet region from the background. We introduce Otsu thresholding method which determines threshold value by minimizing the within-class variance of the two groups of pixels separated by the thresholding operator. This technique is very effective in recognizing the ring frame and wet region. Although the algorithm is limited to the solid woven fabric, its performance is so good that only a little increasing of kernel size of mean filtering is enough for the fabrics of low compactness. For the color-patterned fabrics, further research is needed in the future.

Acknowledgements

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References

1. J. R. Postle and R. Postle, *Textile Asia*, **Feb.**, 63 (1993).
2. K. W. Yeung, Y. Li, and X. Zhang, *Text. Res. J.*, **72**, 693 (2002).
3. "Textile Terms and Definitions", 9th Ed., The Textile Institute, Manchester, 1991.
4. B. Miller in "Surface Characteristics of Fibers and Textiles", (M. J. Schick Ed.), p.417, New York, Marcel Dekker, 1977.
5. I. Holme, "Water-repellency and Waterproofing", in "Textile Finishing", (D. Heywood Ed.), Society of Dyers and Colourists, Bradford, 2003.
6. B. J. Collier and H. H. Epps, "Textile Testing and Analysis", p.253, Prentice-Hall, New Jersey, 1999.
7. P. Grosberg, " Structural Mechanics of Fibers, Yarns and Fabrics", (J. W. S. Hearle, P. Grosberg, and S. Backer Eds.), pp.323-338, Vol. I, Wiley-Interscience, New York,

NY, USA, 1969.
8. C. H. Hsi, R. R. Bresee, and P. A. Annis, *J. Text. Ins.*, **89**, 80 (1998).
9. C. H. Hsi, R. R. Bresee, and P. A. Annis, *J. Text. Ins.*, **89**, 96 (1998).
10. N. Otsu, *IEEE Trans. Systems, Man, Cybernetics,* Vol. SMC-9, 62 (1979).
11. P. V. C. Hough, *U. S. Patent,* 3,069,654 (1962).
12. A. Habib and D. Kelley, *J. Photogrammetric Engineering and Remote Sensing*, **67**, 909 (2001).
13. G. A. Baxes, "Digital Image Processing", John Wiley & Sons Inc., New York, 1994.