# A New Evaluation System for Nonwoven Fabrics Using An Image Analysis Technique Part I: Fiber Orientation*

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## 1. INTRODUCTION

The qualities of nonwoven fabrics are affected by physical and mechanical properties. The mechanical properties depend primarily on the number of fiber-fiber contacts; its porous properties on the number and size of the interfiber spaces; and its optical properties on its density and roughness. The number of fiber-fiber contacts and pores, the size of the pores, and the density and surface roughness are all structural properties. Also, the fiber orientation is an important structural characteristic for maintaining desired properties in the production of nonwoven fabrics.

Visual method is limited by tedious and time-consuming work required in visual examinations. Since computers and various kinds of softwares have been developed, several image analyses have been used for the studies in textiles including the structures of nonwoven fabrics. The data obtained from the images using the image processing is an important information in nonwoven fabrics. Charged Coupled Device(CCD) camera transfers the image of nonwoven fabrics from three to two-dimensional structure. The properties of nonwoven fabrics are evaluated using the structure.

The purpose of this study was to develop a new method with more convenient procedure for evaluating nonwoven fabrics using an image analysis technique.

## 2. EXPERIMENTAL

### 2.1 Materials

Total fifty types of nonwoven fabrics used for coverstocks, filters, and interlinings were used for the main study. They were produced by chemical, meltblown, spunbond, and thermal bonding system. The nonwoven fabrics were made from polypropylene single fibers, bicomponent fibers with polyethylene core/polypropylene sheath, and bleached rayon/polyester blended fibers. The range of the fabric thicknesses was between 0.25 and 0.99 mm and the pressure applied for the measurements of the thicknesses was 0.5 kPa. The fabric mass/unit area ranged between 17 and 36 $g/m^2$.

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## 2.2 Experimental Method

In general, CCD cameras, frame grabbers, and computers are used for digitalizing an image obtained from an object. The system used for this study was the Image Data Acquisition System shown in Figure 1.

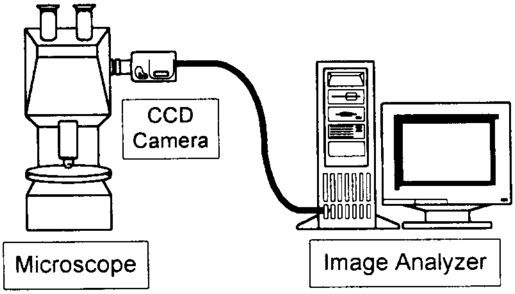



**Figure 1. Schematic Diagram of Image Data Acquisition System**

The system was composed of a microscope (DM RXP, LEICA), a 3-CCD color video camera (DXC-930, SONY), and an image analyzer (Q600S, LEICA) with a frame grabber.

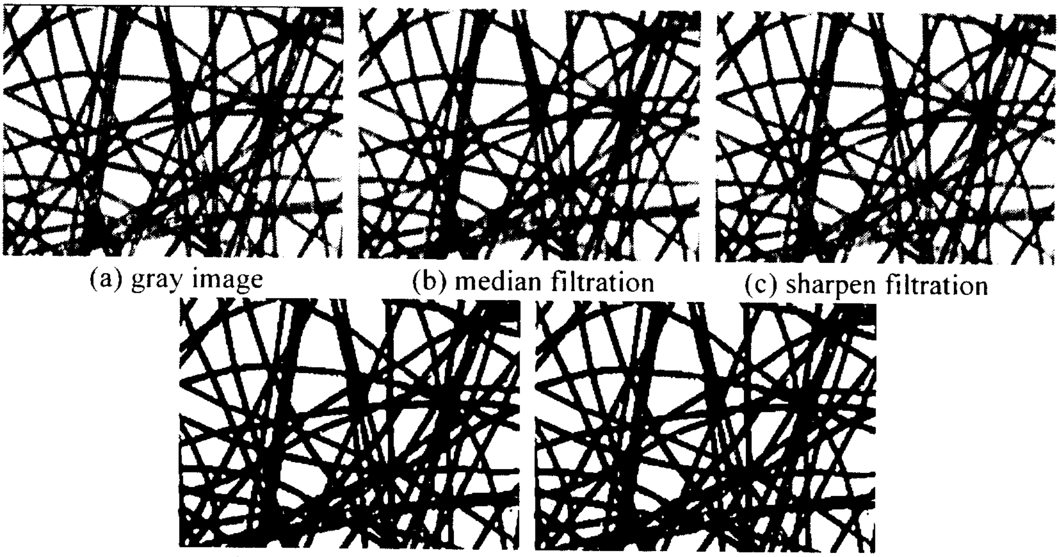
The image processing of the pictorial information (color images) obtained from the CCD camera was conducted carefully without the transformation of the source data. The pixel values of the color images were transferred to 256 gray levels, for fixing the images to the binary values with only fibers and pores. The median filter in Equation 1 was used to remove the electronic noises in the gray image(a), as presented in Figure 2 (b), because the noises could drastically alter the image information.

$$\bar{f}(X,Y) = median(\{-1 \le i \le 1, -1 \le j \le 1 | f(X+I, Y+J)\}) \quad (1)$$

By extracting the edges using the edge detection, the boundaries were more clear than before. In this study, the boundaries between fibers and pores were extracted using the sharpening operator. The sharpening operator in Equation 2 changed the edges by adding the percentage (0.5) of the differences between the pixel values of images.

$$f(i,j) = f(i,j) + 0.5 * (f(i,j) - f(i-1, j-1)) \quad (2)$$

As presented in Figure 2 (c), the changed images increased the slope of the boundaries between fibers and pores. Using the thresholding process, the critical values were decided shown in Figure 2 (d). As presented in Figure 2 (e), the gray images were transformed to the black and white images by the critical value used as a standard.



(a) gray image (b) median filtration (c) sharpen filtration

(d) thresholding image (e) black & white image

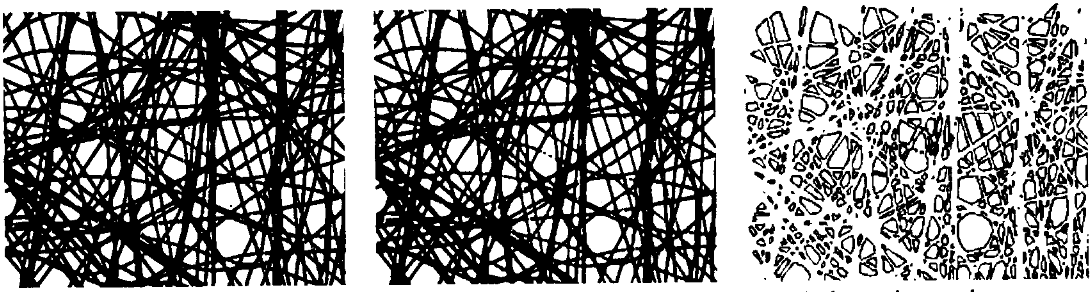
**Figure 2. Image Processing in Nonwoven Fabric**

## 2.3 Detection of Fiber Orientation

It is not easy to analyze the fibers in the images with two dimensional structures because they were overlapped. Therefore, the measurement of the boundaries composed of pores would be necessary. If the fiber orientation around the boundary composed of a pore would be represented to overall fiber orientation, it is possible to predict the overall distribution of fiber orientation. Each edge for the polygons composed of pores depends on the position of fiber. The orientation could be obtained by analyzing the angles between fiber networks consisted of the polygons.

The sampling of fiber orientation was conducted using the image of a polygon as the following method. The pores were extracted for the analysis of the fiber orientation of the nonwoven fabrics. As presented in Figure 3, the outlines of polygons (b) composed of pores were extracted from the black and white images (a). Only polygons (c) were extracted from the outlines of the polygons (b).

A point was made in the center of image. A circle with any radius was compassed with centering on the point. The distribution of the fiber orientations were obtained by measuring the directions of the edges at the points intercepted between the edges composed of polygons and the circle. The range of fiber orientation angles was between 0 and 180°. It was divided by 16 levels and then each range was 11.25°. The absolute values were used for the fiber orientation angles, which were more than 180°, because the fiber orientation angles were symmetric values. For example, if the fiber orientation angle is 210°, the angle used for this study is 30° (180 - 210 = |-30| ).



(a) black & white Image (b) outlines detected from pores (c) detecting polygons

**Figure 3. Pore Detection Processing in the Image of Nonwoven Fabric**

## 3. RESULTS AND DISCUSSION

To predict the tensile modulus of nonwoven fabric from the extracted image, the following model was used in this study. As shown in Figure 4, we assumed that a fiber segment($\ell_i$) of unit area against the small volume of the nonwoven fabric be straight, and the center for each fiber would be randomly distributed in x-y plane. Let the numbers of the fiber segments in the area be $n$. Consider the $i$-th ($1 \le i \le n$, integer) fiber segment of cross-sectional area, $A_i$, modulus, $E_i$, length, $\ell_i$, and the orientation, $\theta_i$. Let the y-directional tensile force acting on the unit area be $\sigma_{nw}$. Consider the small extension of the nonwoven fabric. And let the fiber axial force acting on the $i$-th fiber be $F_i$ and x and y components of $F_i$ be $F_{ix}$ and $F_{iy}$.

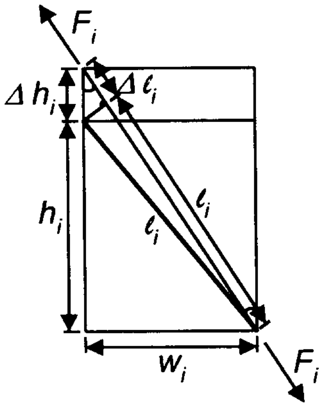



**Figure 4. Model of Theoretical Consideration for Predicting Fiber Orientation**

Equilibrium of forces in x and y directions is same as equations (3) and (4).

$$\sum_{i=1}^{n} F_{ix} = F_1 \sin\theta_1 + F_2 \sin\theta_2 + \cdots + F_n \sin\theta_n = 0 \qquad (3)$$

$$\sum_{i=1}^{n} F_{iy} = F_1 \cos\theta_1 + F_2 \cos\theta_2 + \cdots + F_n \cos\theta_n = \sigma_{nw} \quad (4)$$

In order to obtain the values of $F_i$, consider the following relationship for each fiber :

$$\sigma_i = E_i \varepsilon_i \quad (5)$$

where $\sigma_i$ and $\varepsilon_i$ are the fiber axial tensile stress and strain acting on the $i$-th fiber.

From Figure 4,

$$\Delta\ell_i = \Delta h \cos\theta_i \quad (6)$$

$$\ell_i = h \sec\theta_i \quad (7)$$

where $\Delta\ell_i$ is the increment of the extended length,

$\Delta h$ is the increment of the extended height,

$\ell_i$ is the length of the fiber segment, and

$h$ is the height of the unit area

Here, if we solve equations (4), (5), (6) and (7), the modulus of the fabric $E_{nw}$ is

$$E_{nw} = \frac{E_f}{\upsilon_{nw}} \left( \sum_{i=1}^{n} \cos^3\theta_i \Big/ \sum_{i=1}^{n} \sec\theta_i \right)$$

where $E_f$ is the specific modulus of the fiber and

$\upsilon_{nw}$ is the specific volume of the nonwoven fabric.

Figure 5 presents the distributions of the fiber orientations detected by the manual and new method using samples A and B.

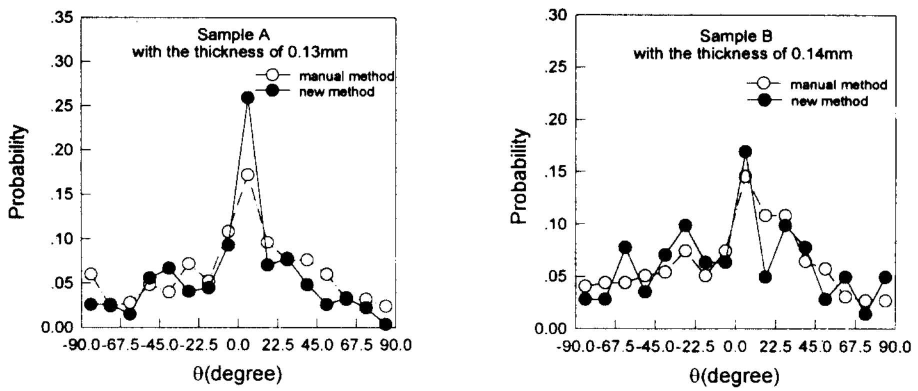



**Figure 5. Distributions of the Fiber Orientations Detected by Manual and New Method**

Comparing between the experimental and theoretical values of the moduli in the samples, the tensile moduli were affected by the fiber orientation as shown in Figure 6. Therefore, the fiber orientation could be measured by the directions of the edges of polygons and the tensile moduli of nonwoven fabrics would be predicted.

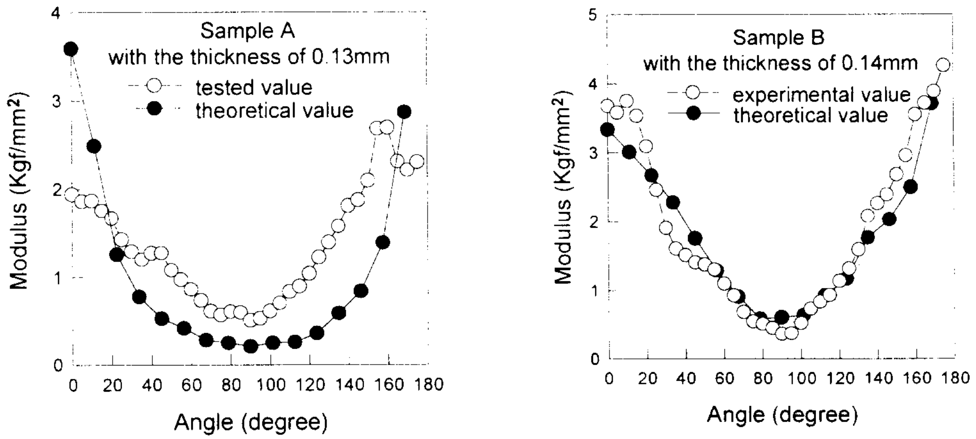



**Figure 6. Comparisons between Experimental Values and Theoretical Values of Moduli in Samples A and B**

## 4. SUMMARY AND CONCLUSIONS

Fifty types of nonwoven fabrics produced by chemical, meltblown, spunbond, and thermal bonding system were used in the study. The tensile properties of the nonwoven fabrics were evaluated by using an image analysis technique.

The conclusions obtained from the study are as follows.

(i) Fiber orientation was predicted by analyzing the directions of the edges in the images composed of the polygons.

(ii) Fiber orientation could be easily predicted using new method.

(iii) The model used for this study fit to the tensile modulus so well.

(iv) New method developed in this study was less time-consuming than the conventional methods, because both pore and orientation were detected from one image easily.

It is necessary to develop the software included the results obtained from the study for the use in nonwoven industries.


## ACKNOWLEDGMENT

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