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Analysis and Measuring Surface Roughness of Nonwovens Using Machine Vision Method

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***Abstract*—**Concerning the measurement of friction properties of textiles and fabrics using Kawabata Evaluation System (KES), whose output is constrained to the surface friction factor of fabric, and no other data would be generated; this research has been conducted to gain information about surface roughness regarding its surface friction factor. To assess roughness properties of light nonwovens, a 3-dimensional model of a surface has been simulated with regular sinuous waves through it as an ideal surface. A new factor was defined, namely Surface Roughness Factor, through comparing roughness properties of simulated surface and real specimens. The relation between the proposed factor and friction factor of specimens has been analyzed by regression, and results showed a meaningful correlation between them. It can be inferred that the new presented factor can be used as an acceptable criterion for evaluating the roughness properties of light nonwoven fabrics.

***Keywords*—**Surface roughness, Nonwoven, Machine vision, Image processing.

I. Introduction

TODAY, image analysis techniques are used in many aspects of engineering works, these techniques have been used in textile and nonwoven technologies to measure and control their different features. Specifically in nonwovens, image analysis is a quite reliable and reputable technique to measure uniformity, cover factor, surface roughness, etc. Some research topics were dedicated to measuring nonwoven mass uniformity and homogeneity as it plays an important role in these fibrous structures [1,2]. There are researches were undertaken to analyze structure of nonwoven fabrics using image analysis [3,4]. In the present work, nonwoven fabrics were modeled into a 3 dimensional structure for measuring their roughness; in fact modeling textile layers to a 3-D format to measure their properties is not a new idea and was also used in other researches [5,6,7]. In a research nonwoven fabrics were simulated in a 3-D virtual structures and a geometric model was considered to simulate nonwoven webs. In another attempt, textiles were modeled to 3 dimensional form to measure their wrinkles by the photometric stereo technique. In addition, Sul *et al*. measured surface roughness using three dimensional profile data. In their system they used box counting method to calculate fractal dimension and then reconstructed an image for obtaining surface roughness data. Moreover, some researchers presented new methods on objective measurement of fabric surface roughness by image analysis. They introduced two parameters derived from fabric images which are fractal dimension calculated by wavelet fractal method and surface average mean curvature. These two parameters describe surface roughness [8,9]. In another study a solution which provides a method to measure roughness-friction criteria of tested surface introduced [10].

Surface roughness in Kawabata is measured by pulling a U-shaped steel wire with 0.5 mm diameter through the fabric length under a normal force of 10 gf. In fact, height is measured by this system, and a height profile of fabric through its length concluded from this experiment. Mean deviation of this profile is considered as surface roughness in Kawabata system.

The problem in Kawabata surface roughness measuring is twofold. First, changes in height along the fabric width are not considered as the height is measured along the fabric width in this system. Second, friction of fabric is not a point of issue in measuring roughness, which plays an important role in roughness. This is mostly because objective of Kawabata from measuring surface roughness is evaluating fabric handle not measuring roughness itself, as a matter of fact, friction coefficient is considered as a criterion of fabric handle but not surface roughness in KES.

In a research presented by Govindaraj, *et al.* a novel method had been proposed to measure fabric roughness which simulate woven fabric surface using two signals. These signals had been generated from friction profile of fabric in two direction of warp-wise and weft-wise, and then these two orthogonal signals have been combined to reconstruct a 3D surface profile of fabric [11]. This method is constrained to fabrics with regular surface i.e. woven fabrics. Hence random structured fabrics such as nonwovens couldn’t be analyzed in these systems from surface roughness point of view; furthermore, a need emerged to measure surface roughness accurately, and simply. These conditions led this research to an image processing based method.

As random textile structures become more and more applicable so today many researches were focused on developing new, simple and fast measurement method for evaluating different characteristics of these layers. As a result, presenting a novel method which can evaluate surface roughness by image processing techniques is essential for the nonwoven industries.

In this research an image processing based method was used to model surface of nonwoven layer by turning their 2-D images into a 3-D structure, and then its surface roughness

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had been measured. Finally its relation with their friction coefficient was investigated.

II. Methods

To evaluate surface roughness a reference is needed which fabric surfaces could be compared to it. In fact this reference is nothing but a layer which presents most pleasant roughness for human tactile sensation, this layer is called ideal surface in this paper.

Ideal surface is a surface with regular sinuous waves with least amplitude and wavelength which could be sensed by human tactile sensation, this surface has the most comfortable handle sense for textiles; moreover, it presents the ideal friction of textiles for human body. As the friction coefficient of textiles are generally related to their touch and handle properties [12,13], the best fabric from roughness point of view was considered a fabric which its height waves correspond with human touch sense.

Surely touch of finger is sensitive to friction therefore in a model the tissue of human finger was simulated and the least range of amplitude and wavelength which human tactile sensation could feel, were measured [14]. According to this research the least sensible wavelength and amplitude of unevenness are equal to 1 mm and 2.5 µm respectively. Fig. 1 depicts an ideal simulated surface according to the mentioned data. Where *x-y* plane is number of pixel matrix and *z* direction is height.

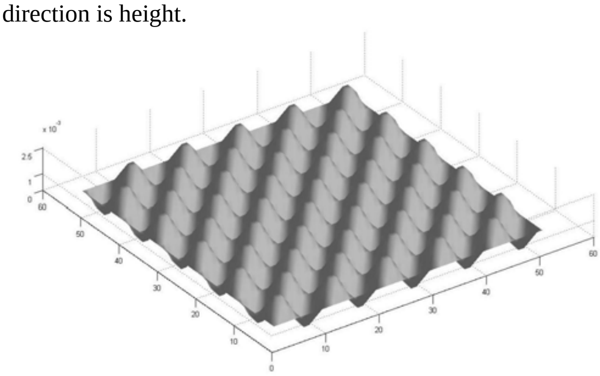

Fig. 1 Ideal simulated surface

All the scanned surfaces were compared to the ideal surface and their differences to the ideal surface were measured according to the following.

To compare real specimens of nonwoven, light spun-bonded nonwoven produced from 0.87 dtex polypropylene fibers was used for this research. First, nonwoven layers were scanned with resolution of 600 DPI using a scanner. Also a black layer was pasted in the scanner for the background of images. The acquired images were converted to the gray scale images with 256 levels and then Wiener and Gaussian filters have been applied on the images to reduce noise through images. In these images, bright zones show dense parts of nonwoven layer and dark zones show sparse parts of layer. Fig. 2 shows scanned images of nonwoven specimens. Fig. 2a shows a nonwoven fabrics and Fig. 2b depicts its histogram equalized image, merely for better vision.

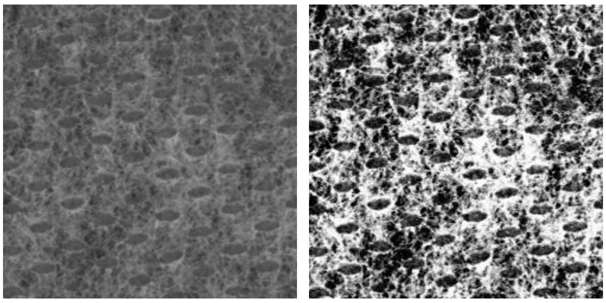

Fig. 2a, 2b Scanned image of light nonwoven fabric

Each pixel in this image was mapped to a point in a height profile. Therefore, a profile of surface had been drawn, and value of each element in this profile is simulated height of that point in the image. The brightest pixel in the image was mapped to the highest point in the profile. As a result, the gray scale which is equal to 255 describes the highest point in the layer which its height is 2.5 µm. This height was chosen due to easily comparing of real specimen and simulated surface and also because all of the surface roughness of specimens had to be compared to friction coefficient of that specimen it is important that all of these images becomes in an individual format. This individual format is the format which also corresponds with ideal simulated surface dimensionally. This would lead to a profile which its height amplitude differ from 0 to 2.5 µm that is like the simulated ideal surface. Fig. 3 shows a simulated surface profile generated by the mentioned algorithm.

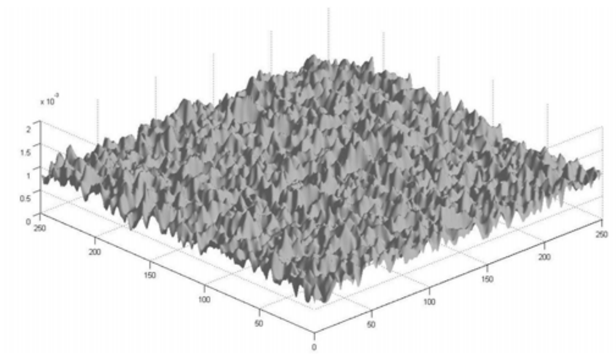

Fig. 3 Simulated surface profile, generated from scanned image

To assess nonwoven layers, five criteria of their profile surface were evaluated. These criteria are 1. *N*: number of peaks on the nonwoven surface, a peak defined as a point which is higher than its 3×3 neighborhood and may it has equal height to some of its neighbors 2. *T*: variance of distance of peaks to origin 3. *E*: volume of simulated profile from image 4. I_d: ratio of variance to mean of gray scale levels of images 5. *V*: variance of gray scale levels of peaks in a profile. These five criteria assist us to define a factor which is called surface roughness factor in this paper and showed with R_s, using these five criteria we could evaluate surface roughness factor. In fact value of each element which represents height value in the simulated profile is used to assess roughness. The idea of using height value to assess roughness is derived from

Kawabata evaluating system. Hence, in Kawabata surface roughness measuring, height profile along its width is used and measuring is line by line but in presented paper, measuring is point by point.

Initial Surface Roughness Factor (R_s):

Five presented criteria had been measured from images, following that step; these criteria have been compared with criteria of simulated ideal surface. And new, *K*-named, criteria obtained from comparing profile with ideal surface. To summing evaluated data from images and concluding them in a single criterion, a factor, R_s, had been calculated for every image using compared data. These compared data had been calculated in the following approach.

$$K_n = \frac{|N_s - N_r|}{N_s} \tag{1}$$

Where *s* index is for the simulated surface and *r* is for profile generated from real surface. This factor demonstrates difference between number of peaks in ideal surface and real surface.

$$K_t = \frac{|T_s - T_r|}{T_s} \tag{2}$$

This factor shows difference between variance of distances of peaks from origin of profile, the (0,0) point, in ideal surface and real surface.

$$K_e = \frac{|E_s - E_r|}{E_s} \tag{3}$$

This factor indicates difference between volume of simulated surface and real surface. In fact volume could be calculated simply by summing the heights values for all of points.

$$K_{I_d} = \frac{|I_{d_s} - I_{d_r}|}{I_{d_s}} \tag{4}$$

This factor shows difference between variance ratio of simulated surface and real surface.

$$K_v = \frac{|V_s - V_r|}{V_s} \tag{5}$$

This factor demonstrates difference in variance of gray scale value of simulated surface and real surface.

Now using these five factors a new criterion had been defined which represents similarity of specimen to ideal simulated surface. This factor considered as initial surface roughness factor, R_s, as presented in formula 6 and its value is between 0 and 1. The 0 value shows no difference between ideal surface and tested specimen and value of 1 shows the most dissimilar specimen to ideal surface.

$$R_s = \frac{K_s + K_t + K_e + K_{I_d} + K_v}{5} \tag{6}$$

This factor had to be calibrated with values of friction coefficient, and effect of friction coefficient had to be considered in evaluating surface roughness. To reach this point, following step has been proposed and value of measured R_s has been calibrated with values of friction for the scanned nonwoven layers and a new factor has been presented which is better for evaluation of roughness due to its inner effect of friction coefficient.

III. Experiments

To evaluate the presented factor, it had been compared with their friction coefficient. To measure friction coefficient of specimens the ASTM D1894 method had been used [15]. Zwick testing machine was used to measure forces during sliding movement. Measuring forces led to measuring friction coefficient, which calculated from dividing average of friction forces by normal force of 28 cN. This normal force is 20 cN more than from which is in standard. Because the nonwoven surface was flatter than expected, the original normal force of standard couldn't demonstrate changes during slide properly so the normal force had been increased. Table I shows measured friction coefficient and also R_s for all of the specimens.

TABLE I
Measured Surface Roughness and Friction Coefficient

Specimen	Surface Roughness	Friction Coefficient
1	0.410	0.395
2	0.376	0.362
3	0.364	0.348
4	0.368	0.347
5	0.384	0.373
6	0.398	0.386
7	0.384	0.378
8	0.378	0.362
9	0.371	0.357
10	0.403	0.394
11	0.369	0.360
12	0.361	0.354
13	0.408	0.401
14	0.389	0.367
15	0.391	0.383
16	0.381	0.371
17	0.384	0.363
18	0.392	0.376
19	0.388	0.375
20	0.387	0.365
21	0.392	0.378
22	0.377	0.359
23	0.393	0.379
24	0.396	0.384
25	0.385	0.368
26	0.397	0.389
27	0.372	0.364
28	0.358	0.344
29	0.393	0.384
30	0.363	0.354

Fig. 4 shows the comparison of R_s and friction coefficient. As it is obvious results showed a meaningful correlation between R_s and friction coefficient.

The regression coefficient between friction coefficient and R_s is 0.901 and confirms that a linear relationship is satisfied between them. Formula 7 demonstrates the linear relationship between friction coefficient and initial surface roughness factor.

$$\mu = 1.027\, R_s - 0.023 \tag{7}$$

Using this formula we are able to introduce a new roughness factor which has effect of friction inside it.

$$R_s' = 1.027\, R_s - 0.023 \tag{8}$$

This R_s' could be an appropriate roughness factor which originally implies both elements of roughness first, height which considered point by point and second, friction coefficient of layers.

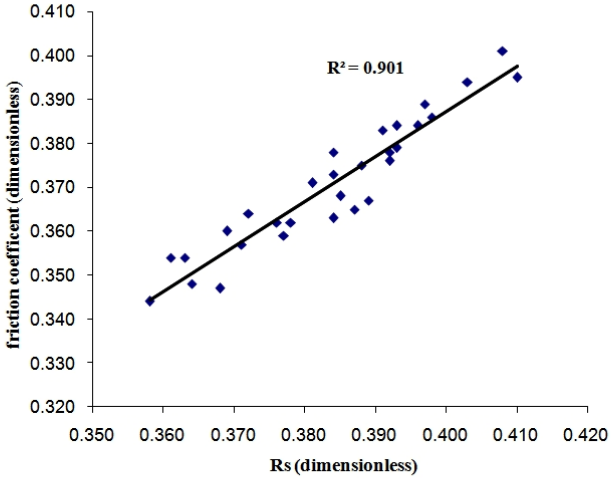

Fig. 4 Relation between friction coefficient and Rs

IV. Conclusion

Image processing could be a reliable method to measure different features of textiles. Some features like surface roughness could be quite tricky using other measurement systems. But image processing deal with surface directly and this would lead to better and more accurate measuring of surface features such as roughness. In this research a novel method presented based upon the processing of scanned images of nonwovens. A factor, R_s, proposed as a criterion which indicates the surface roughness measured by algorithm and simulated profile surface. This factor had a meaningful correlation with friction coefficient. Then a new factor, mentioned as R_s', has been presented which has effect of friction coefficient in it. This R_s' could be a fair factor which shows surface roughness factor of light nonwoven layers.

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