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Surface Roughness Measurement of Weft Knitted Fabrics Using Image Processing

Abstract
This paper focuses on measuring the roughness of knitted fabrics using a non-contact method. Research on objectifying the handle of textile fabrics is a very important factor in textile and garment manufacturing and retailing industries. Fabric handle is influenced by mechanical and surface properties. The KES-F system is a standard objectified method among different measurement methods. However, the KES-F system is time-consuming, and the translation of the data measured is difficult. In addition, the KES-F method as a contact-method is more easily affected by environmental conditions, such as moisture, and is not suitable as an on-line system in the manufacturing process. Hence the surface roughness of knitted fabrics without any deformation was measured by a non-contact method using a high resolution scanner. The data was controlled on a computer by using MATLAB software to obtain the roughness index. The results were compared with the surface characteristic values (SMD) measured by the KES-F system. The findings show a good correlation between fabric roughness values measured by the two different methods. Moreover, a negative correlation coefficient shows that the roughness value measured by Kawabata changes reversely proportional to those measured by the image processing method. Finally, the non-contact measurement of fabric roughness using a high resolution scanner is useful for the description of fabric roughness.

Key words: *image processing, the KES method, non-contact method, surface properties, weft knitted fabric, roughness.*

Introduction

Clothing comfort is one of the major current concerns of textile and garment manufacturers. This attribute is based on the human sensory response to clothing materials and is determined by a variety of thermal, physiological and mechanical parameters. For fabrics that come into direct contact with the skin, touch and tactile properties are especially important in connection with clothing comfort. Important parts of mechanical comfort concern tactile properties, including roughness. There are two reasons for measuring surface roughness: firstly, to control manufacturing, and secondly to help to ensure that products perform well. In the textile branch, the former concerns special finishing, whereas the latter is connected with comfort appearance and handle [1]. The roughness of engineering surfaces has been traditionally measured by the stylus profiling method, creating a surface profile called the surface height variation trace [2, 3]. Modern methods are based on the image processing of surface images of fabric. The surface irregularity of plain textiles has been identified by friction, a contact blade, lateral air flow, a step thickness meter or subjective assessment [1 - 5].

Standard characteristics of a surface profile are based on the relative variability characterised by the variation coefficient (analogy with evaluation of yarns mass unevenness), or simply by the standard deviation. Standardised parameters describing the roughness of technical surfaces are given in the ISO 4287 standard [6]. For characterisation of the roughness of textiles surfaces, the mean absolute deviation (SMD) is usually used.

Many researchers have investigated the surface properties of fabrics, including their friction properties [7 - 13], and have developed instruments to measure fabric surface properties, such as the Kawabata Evaluation System (KES-FB) [14]. This method determines subjective expression by measuring the physical and mechanical properties of textile fabrics and expresses the handle of objectified textile fabrics by analysing a mutual correlation. The KES-F system can conduct measurements of the geometrical roughness and coefficient of friction (μ) of a fabric simultaneously. The sensing element consists of a metallic rod equipped with a thin wire in a U form in its free end [9]. These methods are based on the correlation between subjective sensations, such as smoothness, sleekness, firmness, fullness, crispness and hardness, as well as physical properties such as extension, bending, compression and friction. The variations of handle due to fabric structure and treatments can be measured quantitatively, and the correlation between physical properties and subjective sensation is high. However, the KES method is time-consuming, and the translation of the data measured is difficult. Therefore, simpler methods have been devised, such as the extraction method [11, 12, 16, 17] and sled method [7, 8, 16]. Fabric surface properties have been studied in relation to fabric type, non-flammable treatment and moisture content [11]. The sled method [7, 8] has been used to measure the extensional force stretching two sheets of fabric. Real human fingertips or the back of the hand have also been used to find a more realistic hand force [11]. As contact-type measurements are more easily affected by environmental conditions, such as moisture, and need more measurement time than non-contact methods, they are not suitable for an on-line system in the manufacturing process [1]. Modern methods are based on the image processing of surface images or images of properly bent fabric. The surface irregularity of plain textiles has been identified by friction, a contact blade, lateral air flow, a step thickness meter or subjective assessment [1].

The main aim of this investigation is using a high resolution scanner to evaluate the surface roughness of knitted fabrics. Image analysis is used for extraction of the surface profile. The results obtained from the image analysis were compared with SMD values measured by the Kawabata method. In addition, the effect

Table 1. The knitted fabrics and their specifications.

Code	Yarn properties	Fabric structure	Loop/cm^2	Processing stage
A01	Cotton, Ring, Ne25	Double cross tuck	208	Bleaching
A02		Double cross miss	165	
A03		Plain single jersey	352	
A04			282	
A05			195	
A06		Plain rib	92	Dyeing
A07	Viscose, Ring, Ne25		60	
A08	Cotton, Ring, Ne30	Interlock	268	
A09	Cotton, Ring, Ne24		254	
A10	Cotton, Compact, Ne25	Plain single jersey	314	Bleaching
A11	Cotton, Ring, Ne25		312	
A12	Cotton, Open-end, Ne25		314	
A13	Cotton, Ring, Ne25		310	Bleaching& Softening (2%)
A14			315	Dyeing
A15			310	Bleaching& Softening (4%)

Table 2. Specification of finishing stages.

Processing stages	Description
Bleaching	at 80 °C for 30 minute with Hydrogen peroxide (1.5%) and rinsed
Dyeing	with a reactive dye (Bezative orange S-RL 150) at 60 °C and rinsed
Softening	2 and 4% Tubingal KRE at 40 °C for 20 minute

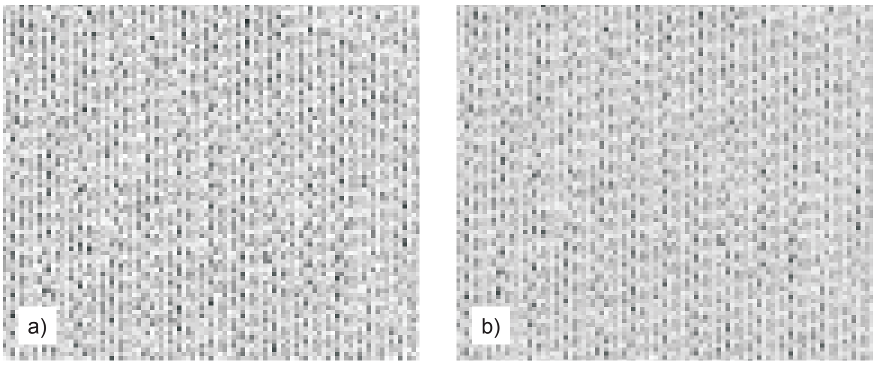

Figure 1. *Sample of knitted fabric image: (a) original image, (b) image after processing by filtering.*

of the fibre, yarn and fabric parameters on the fabric roughness (SMD) was analysed.

Experimental design

Fifteen types of knitted fabrics were used in this study, the specifications of which are shown in ***Table 1***. These knitted fabrics were produced on circular knitting machines with different fibre, yarn and fabric structures. Then the fabrics were treated in different finishing stages. The specifications of the finishing stages are shown in ***Table 2***. The SMD values of the fabric samples were measured by KES-FB4 instruments. For each sample, each measurement was made twice for three separate samples cut from the centre of the knitted fabrics, and the six resulting values were averaged. Standard size samples of 200 mm × 200 mm were tested in the wale and course directions. Because anisotropy is a consideration in knitted fabrics, the surface roughness was measured in both the course and wale directions. Averages of the wale and course measurements were calculated for further analysis. The specimen preparation, pre-conditioning and testing involved standard atmospheric conditions: 20 ± 2 °C temperature and 65 ± 2% relative humidity.

The surface profile of the knitted fabric was scanned using a high resolution scanner. The image area captured was constrained to a size of 10 cm × 10 cm. The roughness of knitted fabric depends on many factors which can be clustered into material and structural factors groups. The effect of the material on surface features is mainly due to the yarn type, which includes yarn count, fibre formation, yarn twist and fibre migration. The structural effect can be considered with certain dimensional parameters of fabric, such as stitch density, loop length and thickness of fabric.

The ideal surface of fabric should not be considered as a flat surface because the surface of fabric is not flat at all. The surface of fabric is supposed to be manufactured well, where the roughness of fabric is well oriented based on the minimum sensible roughness of fabric. In the KES method the probe needle of the device can sense the surface in terms of sensibility. To evaluate surface roughness, a reference is needed to which fabric surfaces could be compared. In fact, this reference is nothing but a layer which presents the most pleasant roughness for human tactile sensation; this layer is called an ideal surface in this paper.

An ideal surface is that with regular sinuous waves of the least amplitude and wavelength which could be sensed by human tactile sensation; this surface has the most comfortable handle sensation for textiles and presents the ideal friction of textiles for the human body. As the friction coefficient of textiles is generally related to their touch and handle properties [2, 6, 18], the best fabric from the roughness point of view was considered to be a fabric whose height waves correspond with the sense of human touch.

The skin of a human finger was simulated, and the least range of amplitude and wavelength which the human tactile sensation could feel were measured [19]. The least sensible wavelength and amplitude of unevenness is modelled according to the fabric structure and can be termed an ideal simulated surface. On an ideal simulated surface, if the x-*y* plane is the number of pixel of the matrices the *z* direction is the height generated from equation (1) based on the thickness of the fabric, than we have:

$$Z = (b - a) \sin(2\pi x) \cdot \cos(2\pi y) + a \quad (1)$$

A sample of an ideal surface is demonstrated in ***Figure 1***.

All the surfaces scanned were compared to the ideal surface, and the differences between the ideal and actual surfaces were measured according to the following stages:

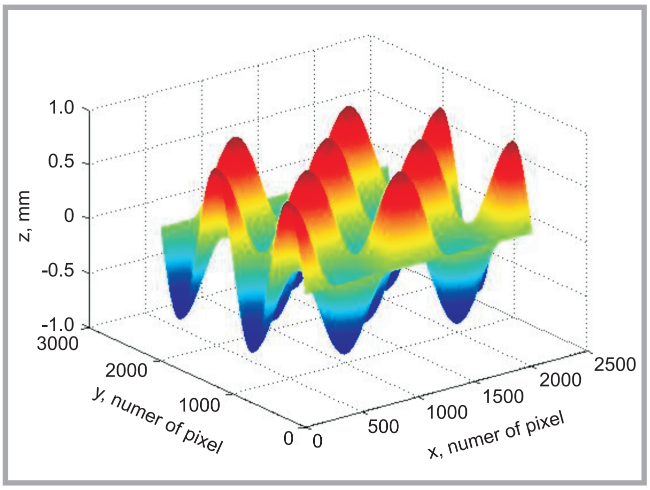

Figure 2. *Schematic sample of ideal simulated surface.*

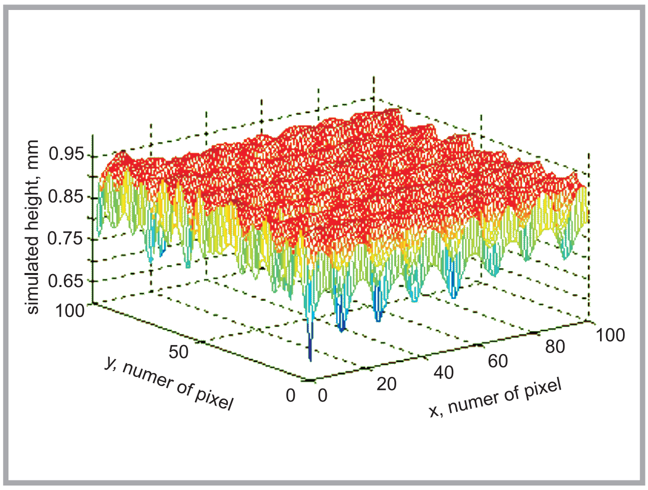

Figure 3. *Sample of simulated surface profile.*

First, knitted fabrics were scanned at a resolution of 600 DPI using a scanner, and a black layer was pasted on the scanner as a background of the images. The back layer is white for dark specimens, therefore those of images should be converted to a reverse image before further image processing. The images acquired were converted into gray scale images with 256 levels, and then Wiener and Gaussian filters were applied to the images to reduce noise in them. In these images, the bright zones show dense parts of the nonwoven layer, and dark zones show sparse parts of the layer. ***Figure 2*** shows a sample of an original scanned image and processed images.

Each pixel in this image was mapped to a point in the height profile. Therefore, a profile of the surface was drawn, and the value of each element in this profile is the 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, whose height is the thickness of the fabric achieved from experiments. This height was chosen in order to easily compare the real specimen and simulated surface, and also because all of the surface roughness of the specimens had to be compared to the friction coefficient of the specimen; hence, it is important that all of these images are made in an individual format. This individual format is one which also corresponds with the ideal simulated surface dimensionally. This would lead to a profile whose height amplitude differs from 0 to the thickness of the fabric, similar to the simulated ideal surface. ***Figure 3*** shows a simulated surface profile generated by the algorithm mentioned.

Five criteria of their profile surface were evaluated to assess the surface roughness. These criteria are as follows: (1) n: number of peaks on the fabric surface, where a peak is defined as a point at which the height is higher than those of its neighbourhood points, and it has equal height to some of its neighbours; (2) v: variance of the distance of peaks to the origin; (3) s: volume of the simulated profile from the image. (4) a: ratio of variance to the mean of the gray scale levels of the images, and (5) g: variance of the gray scale levels of peaks in the profile. In this paper these five criteria help us to define that known as the surface roughness factor, shown as K_t. Using these five criteria, we can evaluate the surface roughness factor. In fact, the value of each element which represents the height value in the simulated profile is used to assess roughness. The idea of using the height value to assess roughness is derived from KES.

Table 3. Criteria of the roughness factor.

Parameter	Formula	Descriptions
K_1	$\frac{n-ni}{n}$	n & ni are the number of peak points in an ideal and real profile
K_2	$\frac{v-vi}{v}$	v & vi are the Variance of the distance vector in an ideal and real profile
K_3	$\frac{s-si}{s}$	s & si arethe Integral of the surface under peaks for an ideal and real profile
K_4	$\frac{a-ai}{a}$	a & ai are the Variance of an ideal and real surface
K_5	$\frac{g-gi}{g}$	g & gi are cv% of an ideal and real surface
K_t	$\frac{K1+K2+K3+K4+K5}{1000}$	Roughness index achieved by image processing

The five criteria presented were measured from the images, and next these criteria were compared with those of the simulated ideal surface. To sum the data evaluated from images and concluding them in a single criterion, the factor K_t was calculated for every image using the data compared, calculated using the equation proposed in ***Table 3***. For each sample, each measurement was made for five separate samples cut from the centre of the knitted fabrics, and the five resulting values were averaged.

Twenty pictures of two different fabrics were evaluated using the T-test hypothesis to ensure the reality and repeatability of the image processing method. The T value is calculated from ***Table 4*** (see page 60). The Matlab Statistical Toolbox was applied to the data measured. For both samples the hypothesis test is appropriate, in which the T values are 0.0096 and 0.0256, respectively. Hence, it can be concluded that the image processing method can measure the roughness index correctly.

Table 4. *Roughness values obtained using twenty different pictures taken of two different samples (A01, A08).*

Picture no.	Roughness value for Sample A01	Roughness value for Sample A08
1	0.1155	0.0457
2	0.1128	0.0472
3	0.1160	0.0410
4	0.0858	0.0427
5	0.1100	0.0406
6	0.1402	0.0386
7	0.1159	0.0349
8	0.1107	0.0475
9	0.0998	0.0424
10	0.1285	0.0420
11	0.1241	0.0340
12	0.1014	0.0514
13	0.1358	0.0482
14	0.1298	0.0438
15	0.1149	0.0438
16	0.1145	0.0446
17	0.1163	0.0389
18	0.1144	0.0407
19	0.1196	0.0538
20	0.0926	0.0450

Table 5. *Roughness values obtained by the Kawabata and image processing methods*

Fabric code	SMD (Kawabata method), µm		Roughness index (K_t) (Image processing)	
	Average	SD	Average	SD
A01	18.74	0.1	0.0457	0.80
A02	12.52	0.9	0.0694	0.75
A03	5.51	0.5	0.1093	0.90
A04	7.98	1.1	0.1042	1.00
A05	8.96	0.8	0.0998	1.20
A06	5.37	1.0	0.1301	0.50
A07	3.57	1.0	0.1402	1.00
A08	5.84	0.9	0.1155	0.65
A09	7.12	0.4	0.1146	0.90
A10	7.34	0.55	0.1023	0.70
A11	6.35	0.8	0.1260	1.30
A12	11.52	0.8	0.0921	1.00
A13	5.59	1.1	0.1324	0.95
A14	6.77	0.9	0.1209	0.85
A15	5.40	0.85	0.1367	0.78

Results and discussion

The SMD values of the knitted fabrics measured by the KES method and roughness index, calculated by the image processing technique, are shown in ***Table 5***.

The surface properties of the fabric depend on several factors, such as the type of fibre, type of spinning system, stitch length etc. Viscose fabrics have a lower SMD value compared with cotton, which is because viscose fibres and yarns have a smoother surface compared with cotton fibres and yarns. The mean values of the SMD value generally decreased as the knit density increased, which may be due to a decrease in the space between stitches while the knit density increases.

The results reveal that SMD values decrease as the knit density increases. Because the gaps within the loops decrease, the surface irregularity of the fabric increases. The values of surface properties increase in the following order based on the knit structure: double cross tuck, double cross miss, and plain single jersey. We can attribute this difference to the feature of plain loops, which appear only in plain single jersey, giving it smoothness and softness. In comparison, tuck loops create a subtle cellular effect on the fabric surface, which contributes to roughness compared with plain single jersey. In double cross miss, miss stitches create longitudinal grooves in the fabric's technical back, resulting in the fabric having rougher handle compared with plain single jersey. The finding shows that the spinning system has a significant effect on fabric roughness. Open-end yarns exhibit higher *SMD* values compared with compact and ring yarns, which may be due to the presence of wrapped fibres, which increase the irregularity of the yarn surface. In the compact spinning system all fibres are perfectly condensed and gathered parallel to each other, thus the yarns present low hairiness and higher values of surface properties, in comparison to ring yarns.

The results reveal that the greatest increase in SMD occurs during bleaching and dyeing, when compared with scoured fabric. The disturbance of surface fibres as well as fabric surface irregularities increase after the bleaching and dyeing processes. In contrast, the values of SMD decrease after the softening process because softeners mask the irregularity of knitted fabrics.

Furthermore the results reveal that an increase in softener concentration reduces the irregularity of the fabric surface and, consequently, the value of SMD. The high temperature and relative movement between the fabric and water in the dye bath create an effect that contributes to fabric surface irregularity. Therefore, the dyed fabric has the highest roughness value.

In order to investigate the correlation between the roughness index calculated by image processing and SMD values measured by the Kawabata method, a regression analysis was carried out using SPSS statistical software. ***Figure 4*** shows the regression plot of this analysis. The correlation coefficient calculated was -0.903, showing a good correlation between the fabric roughness values measured by the two different methods. Moreover the negative correlation coefficient shows that the roughness value measured by Kawabata changes reversely proportional to those measured by the image processing method.

Finally, the non-contact measurement of fabric roughness using a high resolution scanner is useful for the description of fabric roughness.

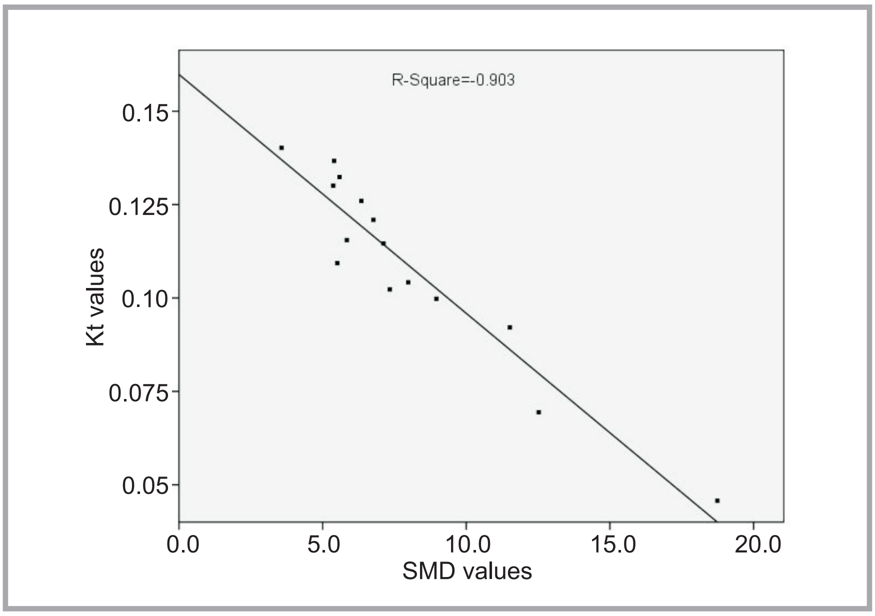

Figure 4. *Relationship between the K-index calculated from image processing and roughness.*

Conclusions

In this paper a high resolution scanner was used to evaluate the surface roughness of weft knitted fabrics. The finding shows that fibre, yarn and fabric parameters influence fabric roughness. The results obtained from the image analysis were compared with SMD values measured by the Kawabata method.

The results show a good correlation between fabric roughness values measured by the two different methods. Moreover, the negative correlation coefficient shows that the roughness value measured by Kawabata changes reversely proportional to those measured by the image processing method.

Finally, the non-contact measurement of fabric roughness using a high resolution scanner is useful for the description of fabric roughness.

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