QUANTIFICATION OF COTTON FABRIC SURFACES

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Abstract

The main aim of this contribution is description of new approach for contact-less evaluation of fabric surface patterns. This approach is based on the image analysis of specially prepared fabric images. For obtaining the surface profile (relative height variation) in the selected direction (on the line transect of the surface) the special arrangements of textile bent around sharp edge is used. The image analysis is used for extraction of surface profile. The system of controlled movement allows obtaining surface profile in two dimensions (surface height variation in the plane). From this information it is possible to estimate the anisotropy of height variation as well. For characterization of surface profile variation the procedures based on power spectral density are used.

Introduction

The surface appearance is important for all kinds of clothing fabrics. A surface pattern of woven structures is in fact sum of periodic components due to weave (waviness) and random fluctuations (roughness). Roughness of engineering surfaces has been traditionally measured by the stylus profiling method creating of surface profile called surface height variation (SHV) trace. Modern methods are based on the image processing of surface images or images of suitably bent fabric. Standard characteristics of surface profile are based on the relative variability characterized by the variation coefficient (analogy with evaluation of yarns mass unevenness) or simply by the standard deviation. Standardized parameters describing roughness of technical surfaces are given in the ISO 4287 norm. For characterization of roughness of textiles surfaces the mean absolute deviation MAD (denoted by Kawabata. as SMD) is usually used. By using KES, the SHV trace of textile fabrics can be obtained. This profile characterizes thickness (height) variation in selected direction (usually warp and weft). Surface irregularity of textiles has been identified by friction (Ajayi, 1992), contact blade (Kawabata, 1980; Ajayi, 1994), lateral air flow (Ajayi, 1988), step thickness meter (Militký & Bajzík, 2000) or subjective assessment (Stockbridge et al., 1957). Modern methods are based on the image processing of surface images (Militký & Mazal, 2007). The image analysis allows genuinely *two-dimensional* data i.e. surface heights in the whole plane.

Standard methods of surface profile evaluation are based on the relative variability characterized by the variation coefficient (analogy with evaluation of yarns mass unevenness) (Militký & Bajzík, 2001) or simply by the standard deviation. This approach is used in Shirley software for evaluation of results for step thickness meter (Anonymous, 1999). For characterization of fabrics roughness the mean absolute deviation MAD (denoted by Kawabata. as SMD) is usually computed (Militký & Bajzík, 2001).

The main aim of this contribution is description of new approach for contact-less evaluation of fabric surface patterns. This approach is based on the image analysis of specially prepared fabric images. For obtaining the surface profile, (relative height variation) in the selected direction (on the line transect of the surface) the special arrangements of textile bent around sharp edge is used. The image analysis is used for extraction of surface profile. The system of controlled movement allows obtaining surface profile in two dimensions (surface height variation in the plane). For characterization of surface profile variation the procedures based on power spectral density are used. Proposed procedures are checked on the practical example of cord fabric.

Non Contact Roughness Evaluation

Relief profile of textile surfaces at given position along machine direction can be obtained from the analysis of specially prepared fabric images. For creation of these images, the apparatus RCM was constructed. This apparatus is fully controlled by PC. For good image creation the suitable lighting (laser from the top) and fabric arrangement (bent around sharp edge) was selected. Result after image treatment is so called "slice" which is the roughness profile in the cross direction at selected position in machine direction (the line transect of the fabric surface). The system RCM offers reconstruction of surface roughness plane in two dimensions. For this purpose, the sample holder is step by step moved in controlled manner. From set of these profiles, it is possible to reconstruct the surface roughness plane. Detailed description of RCM parts and principles is given by Militky and Mazal (Militký & Mazal, 2007).

Classical Roughness Characteristics

Because the basic output from RCM is set of "slices" (roughness profiles in the cross direction at selected position in machine direction) it is possible to compute all profile roughness characteristics separately for each slice and show the differences between slices. Another possibility is to use reconstructed surface roughness plane for evaluation of planar roughness.
There are two reasons for measuring surface roughness. First, is to control manufacture and is to help ensuring that the products perform well. In the textile branch the former is the case of special finishing (e.g. pressing or ironing) but the later is connected with comfort, appearance and hand.
From a general point of view, the rough surface display process has two basic geometrical features:

(1) Random aspect: the rough surface can vary considerably in space in a random manner, and subsequently there is no spatial function being able to describe the geometrical form,
(2) Structural aspect: the variances of roughness are dependent with respect to their spatial positions and their correlation depends on the distance. Especially surface of textile weaves is characterized by nearly repeating patterns and therefore some periodicities are often identified.

The random part of roughness can be suppressed by proper smoothing. In this case the only structural part will be evaluated.

From the individual "slices" it is possible to evaluate a lot of roughness parameters. Classical roughness parameters are based on the set of points $R(d_j)$ $j = 1.\ N$ (heights of surface profile) is defined in the sample length interval L_s. The distances d_j are obviously selected as equidistant and then $R(d_j)$ can be replaced by the variable R_j. For identification of positions in length scale, it is sufficient to know sampling distance $d_s = d_j - d_{j-1} = L_s/N$ for $j>1$. The standard roughness parameters used frequently in practice are (Anonymous, 1977):

(i) Mean Absolute Deviation *MAD*. This parameter is equal to the mean absolute difference of surface heights from average value (R_a). For a surface profile this is given by

$$MAD = \frac{1}{N}\sum_j \left| R_j - \bar{R} \right|$$

This parameter is often useful for quality control and textiles roughness characterization (called SMD by Kawabata (Kawabata, 1980)). However, it does not distinguish between profiles of different shapes. Its properties are known for the case when R_j*'s* are independent identically distributed (i.i.d.) random variables.

(ii) Standard Deviation (Root Mean Square) Value *SD*. This characteristics is given by

$$SD = \sqrt{\frac{1}{N}\sum_j (R_j - \bar{R})^2}$$

Its properties are known for the case when R_j*'s* are independent identically distributed (i.i.d.) random variables. One advantage of SD over MAD is that for normally distributed data can be simple to derive confidence interval and to realize statistical tests. SD is always higher than MAD and for normal data $SD = 1.25\ MAD$. It does not distinguish between profiles of different shapes as well. The parameter *SD* is less suitable than MAD for monitoring certain surfaces having large deviations (corresponding distribution has heavy tail).

(iii) The Standard Deviation of Profile Curvature *PC*. This quantity called often as waviness is defined by the relation

$$PC = \sqrt{\frac{1}{N}\sum_j \left(\frac{d^2 R(x)}{dx^2} \right)_j^2}$$

The curvature is characteristic of a profile shape. The *PS* parameter is useful in tribological applications. The lower the slope the smaller will be the friction and wear. Also, the reflectance property of a surface increases in the case of small *PS* or *PD*.

For the characterization of surface roughness will be probably best to use waviness *PC*.

Surface topography is usually broken down to the three components according to wavelength (or frequency). The long wavelength (low frequency) range variation is denoted as ***form.*** This form component is removed by using models based on the form shape. The low wavelength (high frequency) range variation is denoted as ***roughness*** and medium wavelength range variation separates ***waviness.*** The most common way to separate roughness and waviness is spectral analysis. This analysis is based on the Fourier transformation from space domain *d* to the frequency domain $\omega = 2\pi / d$.

For computation of above-mentioned characteristics the program ROKAW in MATLAB has been created. The following characteristics are computed:
a) Geometric characteristics (Mean absolute deviation *MAD,* mean profile slope *MS,* standard deviation of profile slope *PS,* standard deviation of profile curvature *PC,* ten point average *TP*).
b) Spectral characteristics (Spectral moments, maximal value of PSD and corresponding wavelength).

Spectral Analysis

The primary tool for evaluation of periodicities is expressing of signal *R(d)* by the Fourier series of sine and cosine wave. It is known that periodic function given by equally spaced values R_i, $i = 0, ..., N - 1$ can be generally expressed in the form of Fourier series at Fourier frequencies $f_j = j/N$, $1 \le j \le [N/2]$. If N is odd with $N = 2m + 1$, the Fourier series has form (Quinn & Hannan, 2001)

$$R_i = a_0 + \sum_{k=1}^{m} \left(a_k * \cos(\omega_k * i) + b_k * \sin(\omega_k * i) \right) \quad i = 0,..N\text{-}1 \qquad (1)$$

where $\omega_k = 2 * \pi * f_k = 2 * \pi * k / N \quad k = 1,..m$ $k = 1, ..., m$ are angular frequencies. The eqn. (1) is for known frequencies harmonic linear regression model with $2m + 1$ parameters (intercept and $2m$ sinusoids amplitudes at the m Fourier frequencies). The sinusoid with the *j-th* Fourier frequency completes exactly *j* cycles in the span of the data. Due to selection of Fourier frequencies are all regressors (*sin(.)* and *cos(.)* terms) mutually orthogonal, so that standard least-squares method leads to estimates $a_0 = \overline{R}$ and

$$a_k = \frac{2 * \sum_{i=0}^{N-1} R_i * \cos(\omega_k * i)}{N} \qquad b_k = \frac{2 * \sum_{i=0}^{N-1} R_i * \sin(\omega_k * i)}{N} \qquad k = 1,..m \qquad (2)$$

Basic statistical characteristic in the frequency domain is power spectral density PSD defined as Fourier transform of covariance function.

The simple estimator of power spectral density is called periodogram. The periodogram of an equally spaced series R_i, $i = 0, ..., N - 1$ is defined by equation

$$I(\omega) = \frac{1}{N} \left(\sum_{i=0}^{N-1} R_i * \cos(\omega * i) \right)^2 + \frac{1}{N} \left(\sum_{i=0}^{N-1} R_i * \sin(\omega * i) \right)^2 \qquad (3)$$

and can be expressed in the alternate form

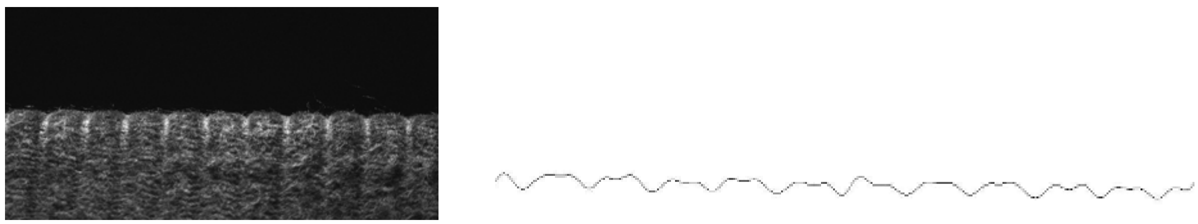
$$I(\omega_k) = \frac{N}{4} (a_k^2 + b_k^2) \quad k = 1,..m \qquad (4)$$

The periodogram ordinates correspond to analysis of variance decomposition into *m* orthogonal terms with *2* degrees of freedom.

The periodogram and power spectral density are primary tool for evaluation of periodicities. Frequency of global maximum on the $I(\omega)$ or $g(\omega)$ graphs is corresponding to the length of repeated pattern and height corresponds to the nonuniformity of this pattern. Spectral density function is therefore generally useful for evaluation of hidden periodicities (Quinn & Hannan, 2001).

Experimental Part

A finished cord cotton fabric with relatively good structural relief was selected for demonstration of relief creation system capability. The original fabric surface is shown on the fig. 1A.



A) B)

Fig. 1 A) Roughness profile in the cross direction of tested fabric and B) corresponding slice after morphological operations and cleaning

Individual relief slices were created by combination of threshold, set of morphological operations (erosion, dilatation) and Fourier smoothing (30 terms) (Militký & Mazal, 2007). Result of these operations is vector of surface heights in cross direction at specified machine direction (see fig. 1B).

Output of data pre-treatment phase is array of slices i.e. array of vectors $R_{j(i)}$ where index i corresponds to the position in j-th slice. From this array it is simple to reconstruct whole surface relief (see. fig. 2).

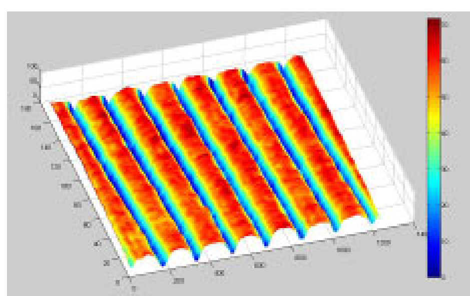
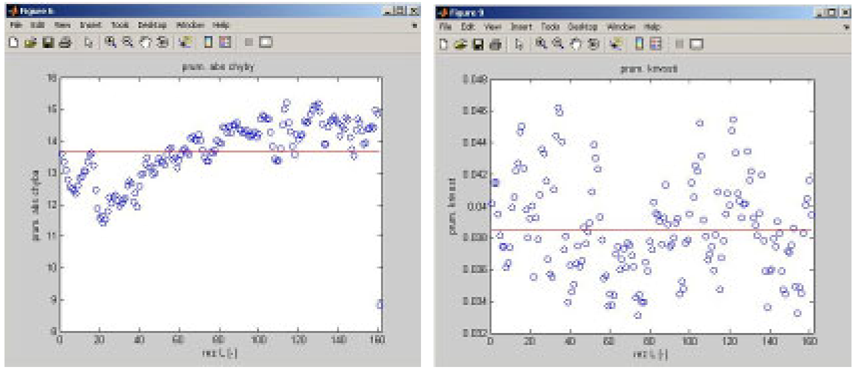


Fig. 2 Reconstructed roughness surface

Results and Discussion

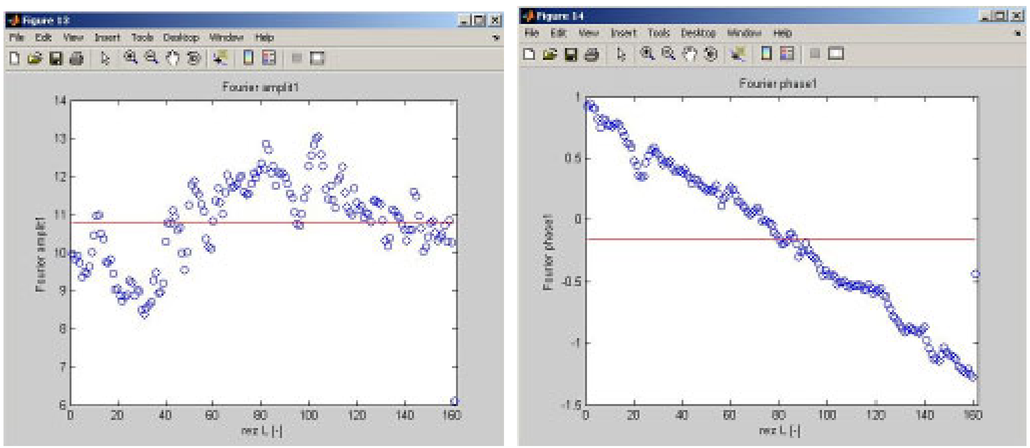
The *MAD* and *PC* characteristics for all slices are shown in the fig. 3.



A) B)

Fig. 3 A) MAD and B) PC values for all slices

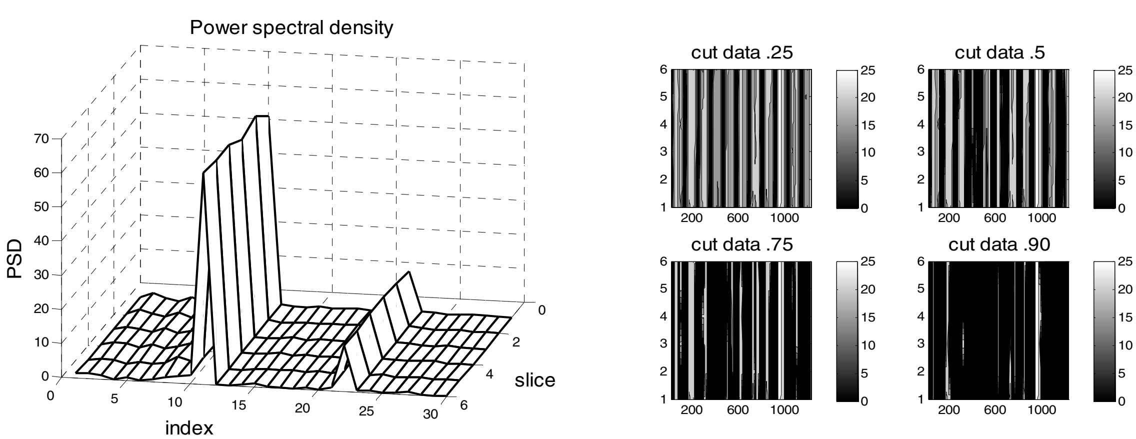
In the case of MAD is visible systematic trend. The variation of PC is nearly random. The amplitude and phase corresponding to the most important Fourier term are shown on the fig. 4.



A) B)

Fig. 4 A) amplitude and B) phase for most important Fourier term

In both cases there are visible trends showing the non randomness of surface profiles. The individual periodograms for all slices are shown on the fig 5A.



A) B)

Fig. 5 A) Periodogram for individual slices, B) surface extremes from indicator variable thresholds

There are visible two maximas in the fig. 5 A) corresponding to the bottoms and tops of cord rows. From very low variation between slices the cord rows uniformity in machine direction is visible. Local variation in the individual rows of cord fabrics are identified by using indicator variable principle. To quantify the relief extremes, one employs so-called *indicator random variables*

$$I(\mathbf{s}, y) = \begin{cases} 1 \ \text{ if } \ y(\mathbf{s}) > Tp \\ 0 \qquad \text{elsewhere} \end{cases}$$

where **s** is spatial position. It is possible to define multiple of these indicator variables for each threshold Tp ($0<Tp<1$). The indicator functions for selected Tp are shown on the fig. 15 b).
It is visible that for higher Tp the local anomalies are readily identified. In the table 1 the mean values of typical measures of relief characteristics for all slices are given.

Table 1. Some characteristics of mean slice roughness

Characteristics	value
PC	0.0337
MAD	5.81
SD	6.955
A_1	1.636
ϕ_1	0.335

Conclusion

The contact-less measurement of cotton fabric images by using of RCM device is useful for description of relief in individual slices and in the whole fabric plane. There exist plenty of roughness characteristics based on standard statistics or analysis of spatial processes, which can be adopted for relief characterization. For evaluation of suitability of these characteristics it will be necessary to compare results from sets of patterned textile surfaces.

Acknowledgements

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