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APPLICATION OF IMAGE ANALYSIS IN THE TEXTILE METROLOGY[*]

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Image analysis is the method for replacement of the human subjective meaning by objective parameters. Digital camera connected with optical devices is used for creation of digital images. This combination enables the investigation of samples in wide scale, from microscopic to macroscopic dimensions. It is possible to use thin (light transparent) samples and thick (nontransparent) ones as well. From point of view of practical applications the sample preparation and interpretation of results are decisive. Image analysis has been successfully used for solving a lot of problems. In this contribution the practical application of image analysis for evaluation of yarns' selected properties and fabric surface roughness are presented.

From the point of view of internal geometry and macroscopic structure textiles are very complex. Their description or modeling requires investigation of some geometric features of longitudinal or cross sectional images. The core problem is identification of typical image feature embedded in the noise. The main problems are:

– blurred images due to techniques of sample preparation, no constant focusing and high level of noise signal;

– poor resolution due to colored background and contacts between individual features;

– presence of non-standard shapes.

Methods of automatic feature detection are not generally applicable and it is still necessary to correct some images manually. It is for example very complicated to identify quantitatively tips on the surface of rotor yarns.

Image analysis techniques in the textile branch are complicated due to high stochastic variability of products. It is necessary to use a huge amount of images from properly selected spots to avoid artifacts.

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Second problem is preparation of digital images containing required structural information. The utilization of special samples, selection of right illumination and viewing angles not only enhance resolution but also are core of success. These problems are specific for textile branch and in many cases are solved by trial and error method only.

Technical problems with preparation of samples based on the optical and technical requirements are similar to digital photography.

In many cases it is necessary to build special models for interpretation of image analysis results or for deeper investigation of obtained information.

The result is that the image analysis methods are still applicable for the research purposes or for identification of faults only. In this contribution the practical application of image analysis for evaluation of yarns' selected properties and fabric surface roughness are presented.

IMAGE ANALYSIS. Image analysis is the method for replacement of the human subjective meaning by objective parameters. Generally, the whole process of image analysis can be divided to five parts:

(1) Sample preparation and pretreatment

(2) Image creation (replacement of classical photography)

(3) Computer assisted image preprocessing (image enhancement, image threshold, and elimination of signal noise, change of brightness)

(4) Image treatment (image coding - compression detection of lines, areas, shape information, saving of data files)

(5) Interpretation and quantification of results.

Parts 3 and 4 realized on the computer by suitable software are the core of so called image analysis. Digital images (part 2) are created by the digital camera connected with suitable optical devices. This combination enables the investigation of samples in wide scale, from microscopic to macroscopic dimensions.

It is possible to use thin (light transparent) samples and thick (nontransparent) ones as well. Image analysis has been successfully used for solving of a lot of problems connected with geometrical characteristics of textile materials. Generally the images can be obtained from surface (longitudinal views) or from cross section (perpendicular views). Individual methods are dependent on the form of material.

Basic fiber characteristics evaluated by image analysis are:

1. Longitudinal views: length, diameter (for round profile), crimping, surface peculiarities.

2. Cross-sections: area, perimeter, fineness, shape factor, specific surface, degree of conversion into ultimate flax fibers, cotton maturity.

Basic yarns characteristics evaluated by image analysis are:

Longitudinal views: hairiness, diameter, surface twist, belt fibers on rotor yarn, cover factor of wrapped core yarn, thickness unevenness, compression between two parallel plates.

Cross-sections: fiber number, packing density, diameter, porosity, blending uniformity, mass (volume) blend portion.

Basic woven fabric characteristics evaluated by image analysis are:

Longitudinal views: cover factor, porosity, surface roughness, hairiness, pilling, abrasion, textural characteristics, surface creasing, and bended fabric shape.

Cross-sections: binding point geometry, thickness.

Examples of image analysis application in the textile metrology area are: trash content and shade uniformity of cotton fibers (Xu et all. (1997)), evaluation of fibers' geometrical characteristics (Xu and Ting (1996)), analysis of yarn thin places and unevenness (Zhang, Iype and Oxenham (1998)), uniformity of weave set (Fisker and Carstensen (1997)), pore size analysis in textiles (Gong and Newton (1992)), drape characterization (Jeong (1998)) and objective characterization of pilling (Hsi, Brese and Annis (1998)).

Yarn cross-section analysis. The analysis of yarn cross-section enables to estimate the fiber number in yarn cross-section, mean yarn-packing density, porosity and yarn diameter. It is possible to construct the radial course of packing density as well.

The important part of the whole analysis is preparation of the yarn cross-sectional images. From various places of yarn fiber cross-sections of thickness about 15 μm were prepared. For preparation of cross-section the soft method (i e. fiber pretreated by glue are sealed by mixture of beeswax and paraffin) was used. The main problem is to obtain images having well defined boundaries of fibers in the whole surface of yarn cross-section. The automatic detection of fibers cross-sections is very complicated and therefore the manual selection and correction of fibers profiles have to be applied (LUCIA D - Laboratory Imaging software was used).

Two methods for yarn packing density evaluation were compared direct method and Secant method (Křemenáková and Rubnerová (2001)). Direct method is based on the detection of real fibers area. Real fiber images have to be pretreated before evaluation. The separation of individual images, transformation to binary form and noise removing is necessary. Secant method requires the measurement of fibers center of gravity only. Other required parameters are fiber fineness and volume density, yarn fineness and twist. The analysis is based on the idealized reconstruction of fibers' cross-sections around their measured center of gravity. By using fiber fineness and mass fiber density the equivalent circle having the same area of cross-section is created and then the correction to the non-circularity caused by the twist and fiber position in yarn is applied.

Yarn Packing Density. Fiber compactness varies at different places in yarn, so that it is reasonable to use the radial packing density curve to characterize the packing density changes from yarn axis to yarn surface. The system of annular rings centered on yarn axis (yarn center of gravity) is used. The packing density is then expressed as function of distance from yarn axis. Local packing density is expressed as the ratio of the fibers' cross sectional area in annular ring to the total area of annular ring.

For comparison of direct method and Secant method the following yarns were selected:

– ring yarn 100% PET fibers, round profile, 20 tex , twist 940 m^{-1} (Fig. 1-a);

– rotor blended yarn 50% cotton / 50% cottonized flax, 24 tex, 1260 m^{-1} (Fig. 1-b).

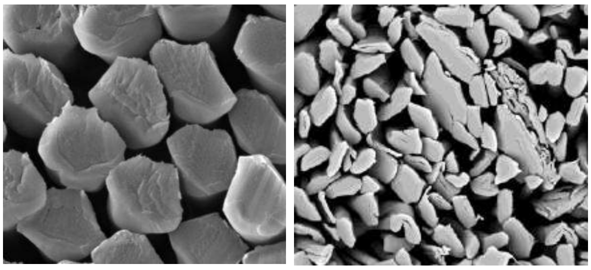

a) PET fibers b) 50%cotton/ 50%cottonized flax fibers

Fig. 1. Cross sections of tested yarns

The lower and upper limits of 95 % confidence intervals for both methods are shown on the Fig. 2 and 3. It is clear that for PET circular fibers it is possible to use Secant method because the packing density traces are similar. In yarn 50% cotton / 50% cottonized flax the cotton fibers of various maturity and bundles of flax ultimate fibers are occurred. In the central part of yarn packing density computed from real cross section shapes is systematically lower (smaller fiber cross sections) and in subsurface layers packing density has the opposite tendency.

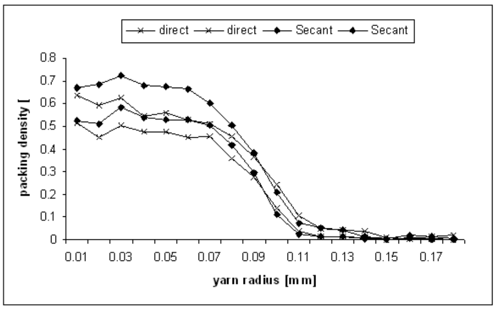


Fig. 2. Comparison of methods – 100% PET yarn

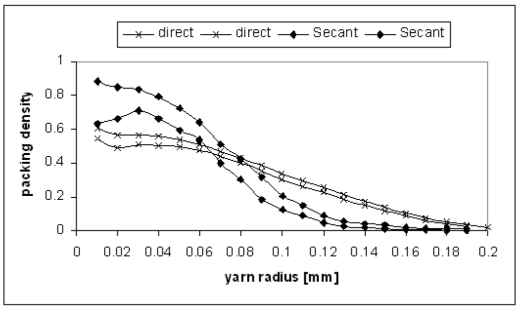
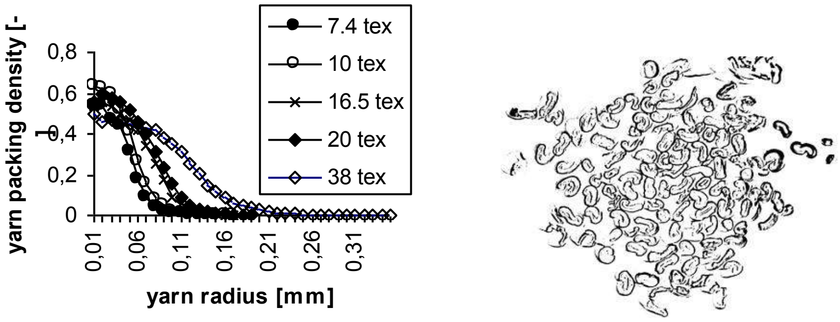


Fig. 3. Comparison of methods – 50%cotton/ 50%cottonized flax fibers

Typical courses of packing density for cotton ring yarns are on the Fig. 4.



a) packing density b) typical yarn cross-section

Fig. 4. Packing density of cotton yarns vs. yarn diameter

Yarn diameter is an intuitive expression. It is often defined by a diameter of imaginary cylinder where fibers are concentrated. Experimentally determined yarn diameter is denoted as effective yarn diameter. It can be estimated for example from a value corresponding to 0.15 of the mean radial packing density or from the value corresponding to 50% of the so-called blackness or hairiness function (explained below). It is useful to express the radial packing density by a single value known as effective packing density. It expresses the ratio between areas of fibers in a circle of effective diameter to the area of this circle. The relationship between yarn diameter and packing density μ has the form

$$d = \sqrt{4T/\pi\mu\rho}\,, \qquad (1)$$

where T is yarn fineness and ρ is fiber mass density.

YARN HAIRINESS. Yarn hairiness can be evaluated from yarn longitudinal images (see Fig. 5). This method is based on the registration of light rays passing through yarn body and creation of so-called darkness density traces (Neckář and Voborová (2003)).

a) free yarn b) flattened yarn with loading 25 N

Fig. 5. Evaluation of yarn diameter and hairiness

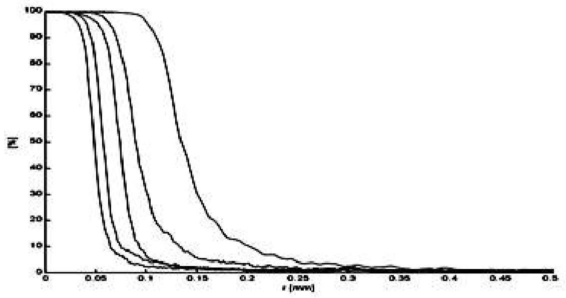


Fig. 6. Darkness intensity traces, ring yarns, fineness from left 7.4, 10, 16.5, 20, 38 tex
Roughness in various domains

Resulting traces for group of cotton ring yarns (see Table 1) are given in the Fig. 6. The main problem is exact definition of yarn diameter as dividing line between yarn body and hairiness area. According to our experiences yarn diameter is situated on 50% values of darkness intensity trace. The influence of spinning technology on the yarn structure and properties can be investigated as well. The description of the darkness density traces is

based on the model curve estimated by statistical analysis (Meloun, Militky and Forina

(1992)).

In the unevenness analysis it is common to aggregate raw data. This is equivalent to cutting the material to pieces and measuring variability between pieces only. In the case of roughness it is aggregation tool for smoothing of roughness profiles and avoiding local (small scale) roughness.

The principle of aggregation is joining of original data z(i) into nonoverlapping blocks or application of window of length L. Aggregated series $z^{(L)}(i)$ are created by the averaging of values z(i) into blocks having L values and characterization of block by mean value

$$z^{(L)}(i)=\frac{1}{L}(z(i*L-L-1+...z(i*L))\ \ L=1,\ 2,\ 3.. \qquad (2)$$

For second order stationary of raw data aggregated series is still second order stationary with auto covariance function $c^{(L)}(d)$ and variance $v^{(L)}$. It is known that variance of aggregated series is connected to covariance function c(d) of original series

$$v^{(L)}=\frac{v}{L}+\frac{2}{L^{2}}\sum_{s=1}^{L-1}\sum_{h=1}^{s}c(d). \qquad (3)$$

Here d is space lag used for computation of covariance function. The nature of original random series can be explained by using characteristics of aggregated series. There are three main groups of series:

1. Series of random independent identically distributed (i.i.d) variables. For this case all c(d) =0, for lags d = 1,2, and data are uncorrelated. This is ideal case for unevenness or random roughness analysis and it is implicitly assumed as valid in majority of methods used in practice.

2. The short-range dependent stationary processes. In this case the sum of all c(d) d = 1, 2, … is convergent.

3. The long-range dependent stationary processes. In this case the sum of all c(d) d = 1, 2, … is divergent.

For short-range dependent stationary processes the first order autocorrelation $R^{(L)}(1)=0$ for $L\to\infty$. The same is valid for autocorrelation of all lags d. The aggregated series $y^{(L)}(i)$ therefore tends to the second order pure noise as $L\to\infty$. For large L variance $v^{(L)}=v/L$. The autocorrelation structure of aggregated series decreases until limit of no correlation. Typical model of short-range processes is autoregressive moving average processes of finite order. For the higher cut lengths are data is approaching to the i.i.d case.

For long-range dependent processes variance $L*v^{(L)}\to\infty$ as $L\to\infty$. The autocorrelation structure is then not vanishing. For these processes it is valid that for sufficiently large L

$$c(d)\approx d^{-\beta}\ \text{and}\ v^{(L)}\approx L^{-\beta}, \qquad (4)$$

where for stationary series $0<\beta<1$ is valid. For no stationary case β can be outside of this interval.

A strictly second order self-similar process has $R^{(L)}(d)=R(d)$ and $v^{(L)}=vL^{-\beta}$. Therefore for the long-range processes correlation structure is identical for original and aggregate series . For strictly second order self-similar processes are $c(d)\approx\frac{v}{2}(1-\beta)(2-\beta)d^{-\beta}$. For the higher cut lengths the correlation structure remains the same and assumption of i.i.d cannot be used. Instead of β the Hurst exponent $H=1\text{-}0{,}5\beta$ is frequently used. When h = 0, this denotes a series of extreme irregularity and h = 1 denotes a smooth series. Exponent h is directly connected to fractal dimension df because in fact $D_F=2-H$ (zhang (1996)).

FABRIC ROUGHNESS. Roughness profile of textile surfaces at given position along machine direction can be obtained from the analysis of specially prepared fabric images. For good image creation it is necessary to select suitable lighting and fabric arrangement (Fig.1). The original RCM system designed for noncontact surface roughness evaluation uses the special arrangements of textile bend around sharp edge (Fig. 2) and laser lighting from the top (Mazal and Militky (2006)). 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 RCM system allows reconstruction of surface roughness plane in two dimensions (Fig. 7). For this purpose, the sample holder is moved (step by step) in controlled manner. From set of these slices it is possible to reconstruct the roughness plane as well.

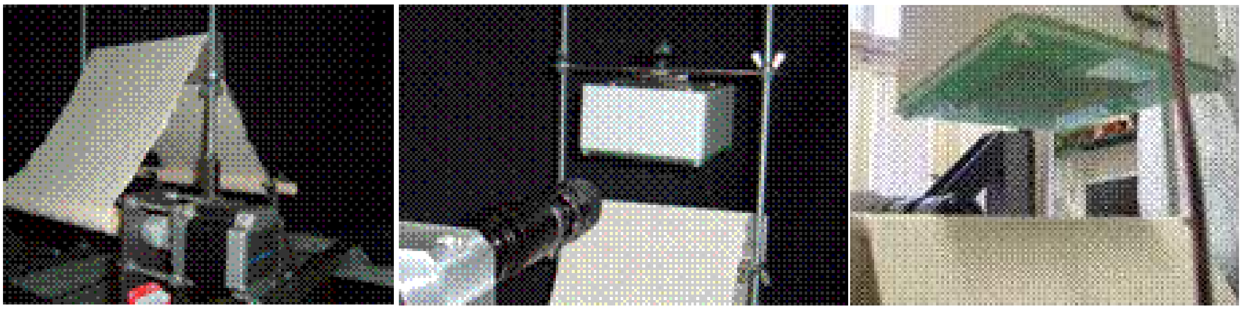
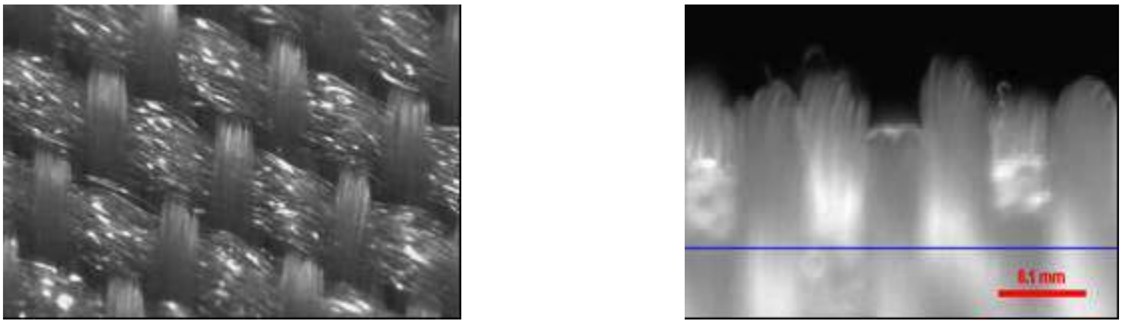


Fig. 7. Details of RCM apparatus

The maximal resolution in roughness slice is 2 μm and basic distance between slices is 76 μm

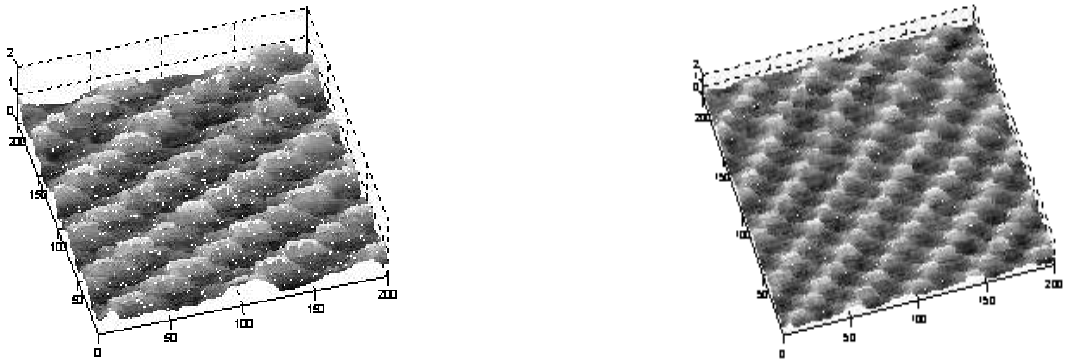
A multifilament filament fabric with relatively good structural homogeneity was selected for demonstration of RCM system capability. The fabric surface is shown on the Fig. 8-a.



a) b)

Fig. 8. Tested fabric: a) – surface view, b) – raw image of one slice

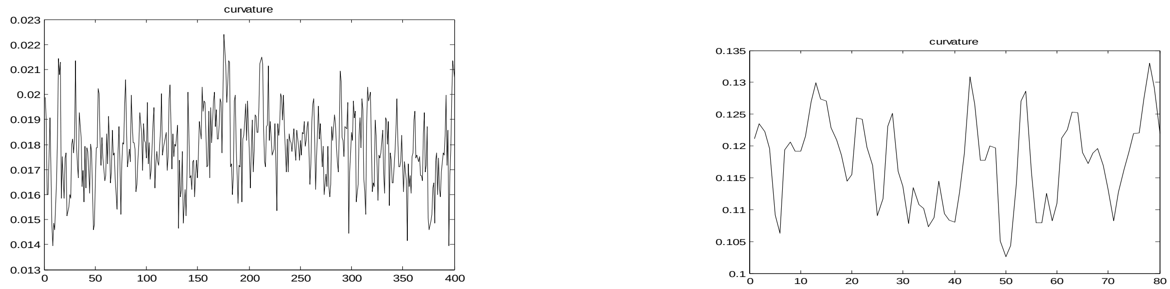
Individual slices roughness profiles were created by using threshold and set of morphological operations. Result of these operations is vector of surface contours in cross direction at specified machine direction. By using aggregation (see eqn(2)) the resolution is decreased and roughness profile is created without local roughness variation. This aggregation has the same function as cut length at unevenness measurement and therefore we use word “cut length X” for the case of aggregation of X subsequent values. After application of cut length principle the direct combination of slices leads to the creation of roughness surface (Fig. 9). The principle of aggregation can be used for smoothing in the machine direction as well (it is equal to the local averaging of slices).



a) b)

Fig. 9. Roughness surface: a) – cut length 1, b) – cut length 10

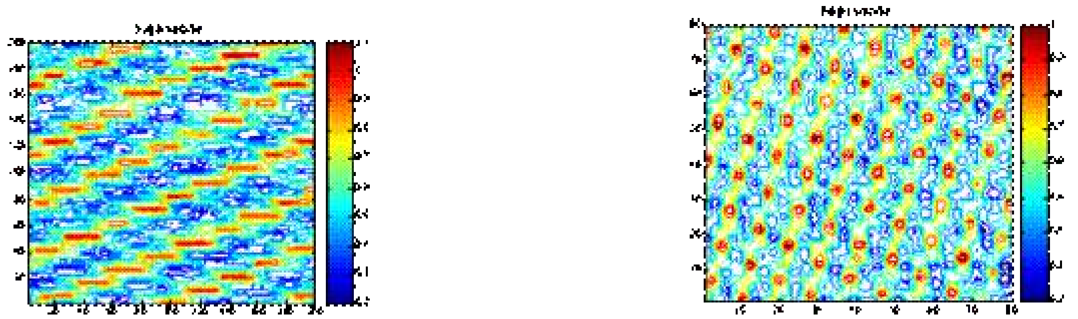
Output from data pretreatment phase is array of slices, i.e. array of vectors Rj(i) where index I corresponds to the position in jth slice. The simplest way to roughness characterization is to use characteristics for individual slices and averaging or plotting characteristics for all slices. For computation of these characteristics the ROSQ program in MATLAB has been created. Some special roughness characteristics are computed (Eke (2000)) also. For illustration of ROSQ capability, the standard deviation of profile curvature PC for cut length 1 and cut length 10 are shown in Fig. 10.



a) b)

Fig. 10. Standard deviation of profile curvature PC of individual slices:
a) – cut length 1, b) – cut length 10

The local rough surface height variation is shown in Fig. 11.



a) b)

Fig. 11. Local rough surface height variation: a) – cut length 1, b) – cut length 10.

CONCLUSIONS

The selected yarns' geometrical properties and fabric surface roughness were investigated by image analysis. The images were processed by the combination of statistical treatment and modeling based on idealized structural arrangement. Results of this analysis can be used for evaluation of textile production quality and for textile design purposes.

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