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Establishing the Course and Wale Density of Knitted Fabrics by a Computer Analysis of 2D Images

Abstract
On the basis of computer image processing analysis, we carried out an assessment of selected knitted fabrics' structure properties by establishing the density of double-layer plain knitted fabrics and plain stitch fabrics. It was noted that the values of correlation ratios between the proposed computer method and the standard method indicate the commensurability of both methods.

Key words: *computer image processing, knitted fabric density, measurement of number of courses and wales, correlation.*

Introduction

The use of computers to analyse a knitted fabric's structure enable tests to be automated and significantly shortened in duration. Computer analysis is not burdened by the many accidental errors which arise in the traditional method of measuring a knitted fabric's basic parameters. Properly selected algorithms of 2D images analysis allow the impact of these errors on test results to be minimised to a great degree. In recent years, many papers have been published regarding the use of various image transformation techniques for assessing the structure, usage parameters and defects in knitted and woven fabrics [1 – 10]. Tests concerning woven fabrics are more advanced in view of their simpler geometric structure. Various variants of Fourier transforms, especially FFT [11], play important roles in image processing and pattern identification. As woven and knitted fabrics contain repeated part elements, the above-mentioned transforms are especially useful. Paper [1] proposed the indirect usage of FFT for establishing woven fabrics' structural parameters, type of weave patterns and skewness. The images analysed were received using a colour scanner. After performing FFT, the double-dimensional image power spectrum was processed. In paper [2], two-dimensional FFT (2D FFT) for identification of pill in textile products was used. The images of the material tested were taken by a 3CCD camera, and were then digitally processed. After the 2D FFT was carried out, the picture was divided into periodic and non-periodic structures, and then by techniques of comparison with the pattern, the extraction of pills was performed. Paper [5] also concerned the problem of pilling. The testing method used is based on the power spectrum analysis obtained during FFT, and uses appropriate masks. In order to decrease the spectrum liking phenomenon, the authors proposed passing the picture through a 2D Tukey-Hanning window. In papers [3, 4], a computer-based method for determining knitted fabrics' density was proposed based on measuring single loop parameters. Furthermore, the proposed methods allowed the stitch structure, the knitted fabric's pattern and the thread diameter to be described. Report [9] is an extension of paper [3], aimed at determining the slurgalling faults of knitted fabrics. In article [6], the system of automatic assessment for knitted fabrics was described, working in LabView environment, which inter alia enables the measurements of course and wale density and unit weight. The advantage of the proposed approach is its possibility to be applied in real time to supervise knitted structures at various stages of the production cycle. In this work, the number of courses and wales is established, as in [3, 4], on the basis of identifying a single loop pattern. In paper [7], an algorithm for determining the angle of spirality was proposed. The knitted fabric images received by scanning are transformed by FFT in order to establish the power spectrum. Next, the directions of courses and wales are established, which enable a description of the necessary angle. Paper [8] described a complex measuring system used in a circular knitting machine, which enabled the detection of defects in knitted fabrics at the production stage. The system cooperates with LabView and MATLAB, and uses two computers, one responsible for capturing the image (at a frequency of 13 Hz), and the other for defect classification. For image transformation, the Gabor wavelet transform was used, and as a classifier a neural network which learned to identify 14 groups of defects was used.

In this paper, the previously developed methods for computer image processing [10] were used to determine selected knitted fabrics' structure parameters,the numbers of courses and wales. To evaluate the efficiency of the method, some statistical investigations were carried out. The proposed measurement method, as opposed to the computer methods presented in [3, 4, 6] based on the measurement of single loop parameters, uses the whole surface of the knitted fabric sample. This allows the measurement process to be significantly sped up and simplified, but the more advanced signal processing method must be used.

Programme, testing material and methods

Test programme

The tests concerned the establishment of the knitted fabric's basic structural parameters containing measurement of course density P_r and wale density P_k according to the standard PN – 85/P-04787 [6] and the proposed original method using computer analysis of 2D images.

Testing material - Types of yarns and characteristics of double-layered knitted fabrics

In order to check the sensitivity of the computer-based method for the determining courses and wales density on

Table 1. The variants of 'plain' double layered knitted fabrics and their structural parameters (course density P_r and wale density P_k) according to PN-85/P-04787.

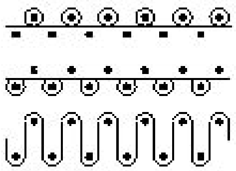
No.	Stitch report	Identification of knitted fabric's variant	P_r, 1/dm	P_k, 1/dm
1.		Cotton15tex//Cotton20tex	158	118
2.		Coolmax20tex//Cotton20tex	151	126
3.		Thermastat20tex//Cotton20tex	149	123
4.		PEScut-Elana13tex//Cotton20tex	148	127
5.		PEScut-Elana20tex//Cotton20tex	148	124
6.		PES167dtexf96//Cotton20tex	152	124
7.		PES167dtexf96//PES110dtexf144	140	130
8.		PA66Skinlife78dtexf68x2FT//Cotton20tex	149	127
9.		PAMerylSpun185dtexf136//Cotton20tex	150	125
10.		PA6660dtexf30//Cotton20tex	148	127
11.		PA66Tasland140texf102//Cotton20tex	145	124
12.		PA78dtexf23x2//Cotton20tex	154	122
13.		PPcięty20tex//Cotton20tex	160	109
14.		PP84dtexf25x2//Cotton20tex	161	112
15.		Trevira167dtexf96//Trevira150dtexf256	128	122

Table 2. The variants of lining double-layered knitted fabrics and their structural parameters (course and wale density) according to PN-85/P-04787.

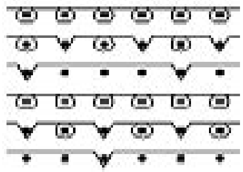
No.	Stitch report	Identification of knitted fabric's variant	P_r, 1/dm	P_k, 1/dm
16.		Coolmax20tex//Cotton20tex-1	157	114
17.		Thermastat20tex//Cotton20tex-1	158	116
18.		PES167dtexf96//Cotton20tex-1	154	112
19.		PA78dtexf23x2//Cotton20tex-1	142	122
20.		Cotton15tex//Cotton20tex-1	161	111

Table 3. The variants of plain-stitch fabrics and their structural parameters (course and wale density) according to PN-85/P-04787.

No.	Identification of knitted fabric's variant	Colour (direct dye)	P_r, l/dm	P_k, l/dm
21.	30%flax/20%PAN/50%viscose 42tex -1	bright beige	70	117
22.	30%flax/20%PAN/50%viscose 42tex -2	beige	84	121
23.	30%flax/20%PAN/50%viscose 42tex -3	brown	89	124
24.	30%flax/20%PAN/50%viscose 42tex -4	blue	89	123
25.	30%flax/20%PAN/50%viscose 42tex -5	grey	86	121
26.	30%flax/20%PAN/50%viscose 42tex -6	black	88	126

the type of raw material, 15 variants of yarns were selected for testing, made of staple and filament fibres (Tables 1 - 3). The main group of tested knitted fabrics contains 'plain' double-layered knitted fabrics made of two plain stitches, shifted within themselves by half a width of wale ('elastic' needles set over), and linked by a tucking technique with the use of textured polyamide thread with a low linear mass PA 22 dtex f7 (Table 1). The raw material, which is first-mentioned, in the symbolic indication were devoted for the first layer of knitted fabric. Apart from double-layered knitted fabrics, lining knitted fabrics were selected for the tests. The types of lining threads are mentioned first in the indication notation (Table 2). The third group contains classical plain stitch fabrics. In order to check the sensitivity of the proposed computer method on the colour, these samples were made in six colour variants (Table 3).

Testing methods - authors' method for establishing knitted fabrics' density based on computer image transformation

A draft of the measurement system built from a PC computer, video card and Panasonic WV-BP 332EE CCTV camera is shown in Figure 1. The system software contains two separate applications: Textil2D, which is responsible for capturing the images from video cameras, and Loo2D, which is used to analyse 2D images.

The computer measurement of number of courses and wales is based on the basic knitted fabric properties, on regular repeating of loops. The regularity appear in vertical and horizontal direction. Figure 2 shows an example image of knitted fabric with marked wales and courses. The wale is represented by a continuous line, and a single course by a broken line. It is easy to notice that the wales are very regularly set, parallel to the sides of the image and themselves. This set of knitted fabrics regarding side edges is the best for obtaining repeated photos for all the knitted fabrics tested. The course in knitted fabric can be set in various ways, from a straight line to

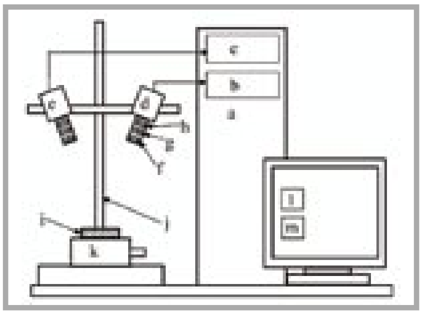


Figure 1. Measurement system: a) PC computer, b) video card No.1, c) video card No.2, d) video camera No.1, e) video camera No.2, f) focus setting, g) zoom setting, h) diaphragm setting, i) sample of tested material, j) stand, k) micrometrical table with light, l) Textil2D application, m) application Loo2D application.

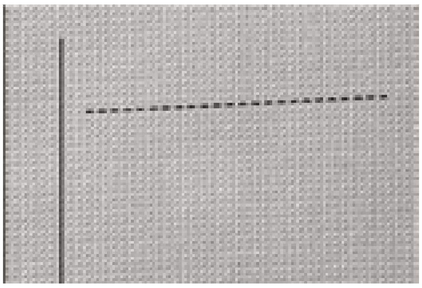


Figure 2. Example picture of number of courses and wales measurement with marked wale line (continuous line) and course (broken line).

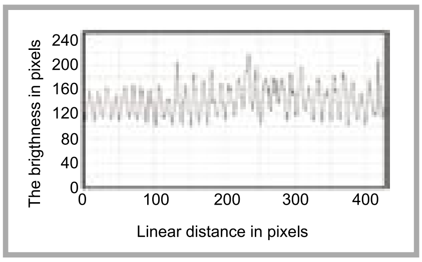


Figure 3. Pixels' brightness along wale marked in Figure 2.

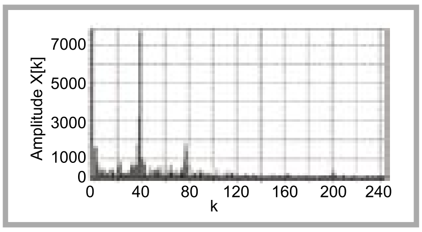


Figure 4. *The diagram of amplitude X[k] in a function k for 36 lines of the image for n=480 image resolution in vertical with the highest amplitude for k=39.*

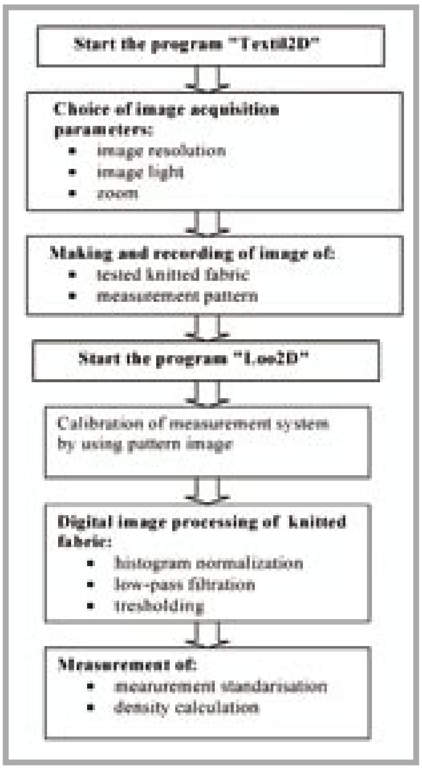


Figure 5. *Block diagram of measurement method.*

a 'wavy' line, and from a parallel to a crosswise setting regarding the bottom and top of picture. In Figure 2 courses are set along a straight line at an angle of about 5° to the bottom edge.

The knitted fabric set as in Figure 2 was a base for describing the algorithm counting courses and wales. The measurement of courses is realised along any selected line describing the position of the wale in the image. In Figure 3, the diagram of the image's pixels brightness changes along the selected wale is presented.

Figure 3 shows that the pixels' brightness waveform is periodical. The minimum are dark places inside a loop, and the maximum is presented by a well-lit yarn. So, to describe the number of courses along the selected wale, it is necessary to count the number of periods for a particular section. For this aim a discrete Fourier transform (DFT) was used [11]. The discrete Fourier transform as an operation on N-dimensional vector (in his case of integers) $x[n]$, $n = 0, ..., N-1$, is an N-dimensional vector of complex numbers $X[k]$ with elements described by the equation:

$$X[k] = \sum_{n=0}^{N-1} x[n] e^{-j\frac{2\pi k}{N}n} \quad (1)$$

Finding the index k, for which the complex number module (hereafter referred to as the amplitude for short) $X[k]$ has the maximum value, the number of courses on the particular section is received. To illustrate the method of measurement in Figure 4, the diagram of amplitude $X[k]$ in function k is presented, from which it results that the maximum value $X[k]$ is $k = 39$, so for 480 pixels, this is 39 courses. The measurement of wales requires a more complex method. As described above, the courses are irregularly set regarding themselves and the picture. It is impossible to use the discrete Fourier transform directly to describe the number of wales. However, if the middle of the wale is identified by a complex number (its amplitude) with a number k, after making DFT for all the vertical lines of the image and creating a new vector of elements suited for the index k, the diagram of amplitude of this vector's elements will be the variables' process with frequency of the wales' appearance. For the generated data, repeated DFT analysis connected with searching for the element of the vector with maximum amplitude will allow the number of wales for a particular length in pixels to be described. Table 4 shows the estimated values in the steps presented above, as well as the way of number of courses and wales standarisation. The process of standardisation is intended to describe the number of courses and wales on the length of 100 mm, for example. It is thus necessary to calibrate the image from pixel number to unit of length. To this end, the system is calibrated by taking the pattern with a known length, enabling a description of the scale, and thus the number of pixels for 1mm of the real image. The block diagram of the proposed measurement method is presented in Figure 5.

Tests results and their analysis

Figure 6 shows the test results of course and wale density obtained on the basis of the proposed computer method, and

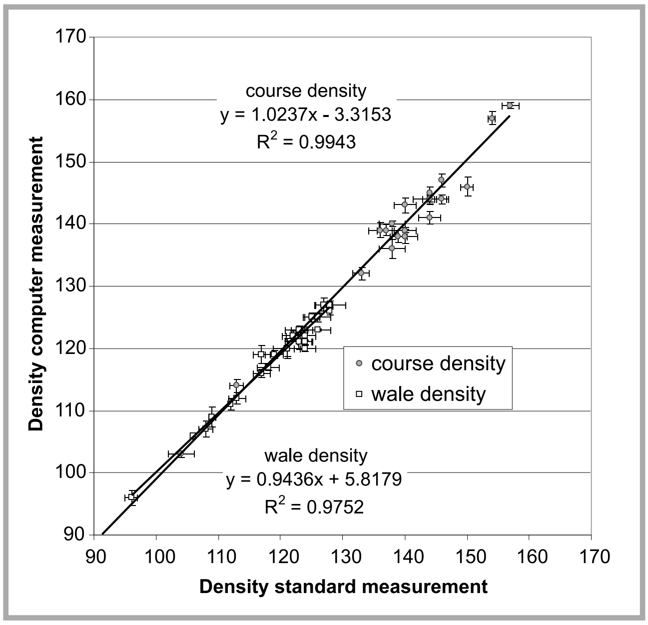


Figure 6. *Shows the test results of course and wale density obtained on the basis of the proposed computer method, and on the basis of the classical method according to standard PN -85/P-04787.*

Table 4. *The results of number of courses and wales measurement for example sample and way of standarisation.*

	Number k	Length in pixels	Scale, 1/mm	Length, mm	Number after standarisation
Courses	39	480	17.20	480/17.2=27.9	L_r=100/27.9*39=139.78
Wales	40	640	17.27	640/17.27=37.1	L_k=100/37.1*40=107.81

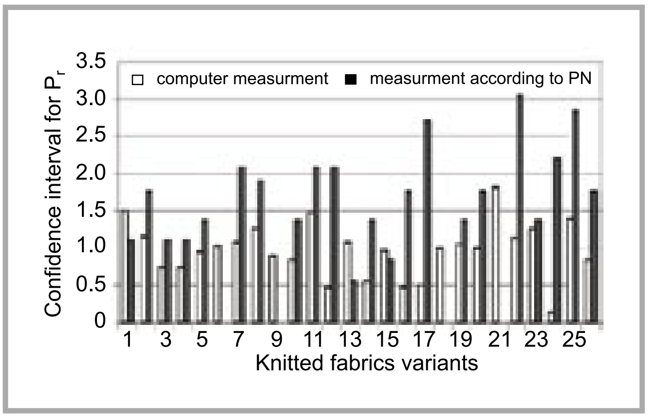


Figure 7. The values of confidence interval for course density results P_r established by computer method and according to standard PN-85/P-04787.

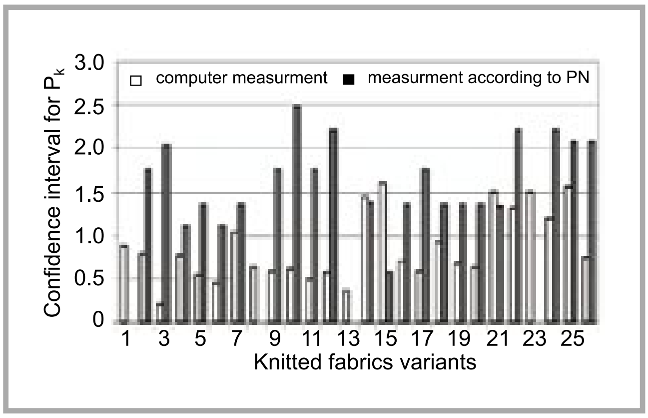


Figure 8. The values of confidence interval for wale density results P_k established by computer method and according to standard PN-85/P-04787.

on the basis of the classical method according to standard PN-85/P-04787.

The values of linear correlation indexes between results obtained by the above-mentioned methods fall within the range of 0.987 to 0.997, where a slightly higher value of correlation index was obtained for the measurement of course density. This is because the wale density measurement requires a more complex method, because courses are irregularly set regarding themselves and the picture. It is not possible to use the Fourier discrete transform directly for estimating the number of wales without first establishing the number of courses. This causes an accumulation of measurement errors. The estimated values of correlation indexes show the commensurability of both measurement methods. The received tests results also indicate that the type of stitch, raw material and colour of knitted fabric do not have any impact on the precision of tests by the method of counting courses and wales with a computer.
The proposed method based on computer counting courses and wales is characterised by a smaller dispersion of density test results in comparison with the standard method for most variants of knitted fabrics. Only for 7 variants were greater values of confidence interval obtained in the case of the computer-based method (Figures 7 and 8).

Conclusions

- The values of course and wale density in plain, lining and double-layered knitted fabrics as established by the computer image-processing method are accordant to the results obtained by the standard method, as is confirmed by the value of correlation index falling within the range of 0.98 to 0.99, where a slightly higher value of correlation index was obtained for course density measurement. The value of correlation index between the test results obtained according to both procedures shows the commensurability of these methods.

- The established values of confidence interval confirm the smaller dispersion of test results obtained by the computer method than obtained by the traditional method.

- The proposed method for automatic counting of the number of courses and wales by computer analysis of 2D images with the usage of a discrete Fourier transform (DFT) enables us to significantly speed up the process of testing the knitted fabrics' basic structural parameters.

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References

1. Xu B., 'Identifying fabric structure with fast Fourier transform techniques', Textile Research Journal, vol. 66, No. 8, pp.496-506, 1996.
2. Xu B., 'Instrumental evaluation of fabric pilling', Journal of Textile Institute, vol.88, pp.488-500, 1997.
3. Perzyna M., 'Geometry estimation of the knitting fabrics structure elements by computer image analysis'. Przegl. Włókienniczy (in Polish), No. 5, pp. 24-26, 2000.
4. Mikołajczyk Z., Włodarczyk B., 'Computer techniques of picture transformation in knitted fabrics structure analysis', Przegląd Włókienniczy (in Polish), 16-20, No. 10, 2000.
5. Jensen K.L., Carstensen J. M., 'Fuzz and pills evaluated on knitted textiles by image analysis', Textile Research Journal, vol. 72, No. 1, pp. 34-39, 2002.
6. Abou-Liana M., Youssef S., Pastore C., Gowayed Y., 'Assessing structural changes in knits during processing', Textile Research Journal, vol. 73, No.6, pp.535-540, 2003.
7. Celik O., Ucar N., Ertugrui S., 'Determination of spirality in knitted fabrics by image analyses', Fibres & Textiles in Eastern Europe, vol. 13, No. 3, pp.47-49, 2005.
8. Ghazi Saeidi R., Latifi M., Shaikhzadeh Najar S., Ghazi Saeidi A., 'Computer vision-aided fabric inspection system for on-circular knitting machine', Textile Research Journal, vol. 75, No. 6, pp. 492-497, 2005.
9. Perzyna M., 'Theoretical and empirical estimation of plain-stitch fabric slurgalling', Fibres & Textiles in Eastern Europe, vol. 13, No. 5, pp.44-45, 2005.
10. Wilbik-Hałgas B., Danych R., Więcek B., Kowalski K., 'Air and water vapour permeability in double layered knitted fabrics with different raw materials', Fibres & Textiles in Eastern Europe, vol. 14. No. 3, pp. 77 - 80, 2006.
11. Chen W.K.: 'Linear Networks and Systems. Algorithms and Computers-Aided. Implementations. Volume 2 - Fourier analysis and state equations', World Scientific, 1990.
12. Knitted fabrics and knitted products. Establishment of number of courses and wales. PN-85/P-04787.

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