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Application of the Image Analysis Technique for Estimating the Dimensions of Spliced Connections of Yarn-Ends

Abstract
In order to determine the geometrical dimensions of the spliced connections of yarn-ends, an algorithm was elaborated using the image analysis technique to determine their dimensions. By applying a Laplace filter, an optimum quality of images with distinguished regions of homogeneity was achieved. The 'Arithmetic Operations' procedure was used to determine the geometrical dimensions of the spliced yarn-ends, and the small random error values (below 0.6%) of the average value of measurement results give evidence of the high repeatability of the results. The algorithm of image digitalisation we proposed, together with measurements of the geometry of spliced connections of yarn ends, enabled their identification. The connection of yarn-ends by splicing was realised with the use of the Jointair 4941 splicing-device from Mesdan.

Key words: *digital image acquirement, image correction, median filtration, Laplace filter, threshold function, digitalisation algorithm, yarn-ends, spliced connections.*

Introduction

The current development of textile science and industry is directed at continuously increasing the quality of the products manufactured. The quality of ready-made products begins with the purchase of raw material, which is then processed at the subsequent production stages [1].

The quality level of the product depends to a very high degree on the modernity of the machine equipment, but also on adherence to technological rules and suitable organisation of the production [1-3]. The spinning process is one of the most important processes in manufacturing textiles, and even at this stage special attention should be paid to yarn quality, especially considering its ability to be processed. Yarn should be characterised by optimal production features, which among other factors means an optimum fitting of the machine's working parameters to the physical properties of the processed fibres, and the minimum number of faults. While spinning with the use of ring-spinning frames, the connections of broken yarns are mostly carried out by hand, and only very rarely by connecting devices. The degree of complexity and the high price of such devices often exceed the spinning mills' financial ability, and so their managements decide to eliminate the breakages by hand. However, considering the increasing demand for yarns, and for their ability to be further processed, elimination of breakages by hand alone is unsatisfactory [4].

The technique of pneumatic splicing is most often applied in the world textile industry for yarn-end connection, taking into consideration the low exploitation costs and the small dimensions of such devices. Splicing-devices manufactured by Mesdan are most often used in Poland.

Devices which eliminate breakages are mostly installed for automatic winders, where they are used to connect yarns whose continuity has been broken as result of cleaning, changing spinning cops, and random breakages [5].

Our intention is to use knot-free yarn connections in order to obtain a joint whose external view and physical properties maximally resemble the appearance and properties of the remaining yarn parts. However, obtaining this kind of 'ideal' joint by the splicing process alone is not possible.

Enterprises which manufacture splicing chambers deliver an instruction manual together with the device describing the standard settings which are recommended for a given yarn assortment. However, taking into consideration the specific yam features, it is not possible to explicitly establish rules for setting up the splicing device. Up to the present, those companies which have produced splicing devices have not elaborated methods of estimation or criteria for yarns with spliced joints. The features of spliced yarn-end joints are determined in spinning mills by organoleptic methods, while greatest attention is paid to the method of yarn-end preparation, and the visual effect of the connection itself. According to specialised enterprises [4, 6, 7], the fluctuation of physical yarn properties with similar linear densities may influence the selection of the most appropriate settings for the device. The final choice of setting parameters always remains in the hands of the technologists, who are specialists in this field. According to the producers [4, 6, 7], preparing the yarn-ends 'ideally' consists in such a method which guarantees that within connecting the yarn-ends, an even, durable joint is obtained, whose diameter is only slightly greater than the yarn diameter, and in which no protruding fibres exist. The connections should have a similar length, the splicing should be well closed (i.e. without clearances, and of a compact and uniform structure), and no damage should appear in the connection zone.

On the basis of a review of the literature, we have established that at present the quality estimation of spliced yarn-ends consists in the following activities:
- analysing the static strength properties,
- estimating the yarn-ends connections resistance against bending and abrasion,
- estimating the resistance against pulsatory stretching,
- estimating the basic geometrical dimensions, and
- organoleptic estimation.

The knot-free connection of yarn-ends has been the subject of investigations by the following researchers: Lünenschloss [8, 9], Bissman [10], Gebald [11 - 13], Kaushik, Hari & Sharma [14 - 18], Neogi & Bhattacharyya [22], and Cheng & Lam [25 - 27]. In Poland, this problem has been examined by Frontczak-Wasiak

& Snycerski [18 - 21], Machnio & Drobina [23, 24], and Lewandowski [28].

All these researchers have used classical estimation methods for determining the quality of spliced connections of yarn-ends according to the above-listed activities. On the basis of the literature considering this problem, we can state that the digital image analysing technique has not hitherto been applied for to estimate yarn-end connections.

The broad, interdisciplinary field of image technique covers ever greater fields of theoretical and experimental knowledge, of knowledge of design and technology, systems, hardware, and software. The dynamic development of image technique has caused its application area to broaden, and covers other fields of knowledge, including textile science and praxis. Currently, it results from the development of material engineering and technology, as well as from digital techniques and computer engineering. The image analysing technique is not a new investigation method. Over a long preliminary period, optics had a fundamental impact on the formation and development of this field of science, firstly as a part of physics, and next as a part of technique. From this point of view, information science & technology and microprocessor technique have played an important role in this field. The image processing technique includes the following concepts [29]:

- image processing, which includes changing the image or sequences of a given image characterised by certain features, into images of other desired features
- image recognition, with the aim of identifying selected image features and objects, which are the subject of interest; image recognition enables image selection, and
- computer graphics, with the aim of creating images on the basis of the assumed description.

The new possibilities for applying image processing techniques make it possible to analyse measurement results of the fibres' surface areas, estimate the irregularity of fibre mixing on the surface of yarn blends, estimate cotton maturity and the damage to wool fibres. These problems have been investigated by such researchers as Berlin, Worley & Raey [30], Thibodeaux & Evans [31], Watanabe, Kurosaki & Konoda [32], Zhao, Johnson & Willard [33], and Żurek, Krucińska & Adrian [34].

The rapid development of image processing techniques has created opportunities to begin research into new procedures of this analysis.

A new quality of the digital image analysis was introduced by the work of Wood [35], and Wu, Pourdeyohomi & Spivak [36], who applied digital image analysis to estimate the quality of carpets during usage. These researchers used frequency methods based on the Fourier transform for image analysis. Thanks to this new procedure, it became possible to identify structural faults. An algorithm for image digitisation, which served to estimate morphological nonwoven features such as porosity, fibre orientation distribution in the nonwoven, and estimation of the fibres' regularity distribution in webs, has been developed by Huang & Bresee [38]. These researchers also applied an automatic measurement process to the image correction procedure by using the procedure of grey-scale thresholding.

Zhang & Bresee [38] compared various image analysis techniques aimed at recognising and classifying yarn joints and thick places occurring in woven fabrics. They applied image segmentation using the threshold values of the object mask, and also carried out procedures of image quality improvement using correction operations such as histogram levelling, autocorrelation, erosion, and dilatation. They stated that applying image correction by the method of statistically determining the image's grey level (the threshold procedure) is more efficient than morphological operations using simple procedures of removing the differences of the object mask by erosion or dilatation. According to Zhang & Bresee [38], applying morphological methods for the image processing technique requires greater calculation power compared with statistical methods, considering the higher quality which is demanded for processing the image mask. Owczarek & Masajtis [39] also investigated, by comparative analysis, the methods of improving the image quality. In order to perform this analysis, they selected ten woven fabric images which had been programmed and intentionally disturbed. The results of the quality improvement operation were estimated with the use of the authors' original program. The numerical values obtained and their verification were the basis for estimating the usability of the digital image analysis. The authors stated that the best results of image correction could be obtained using the histogram modification method.

Cybulska [40] and Masajtis [41] elaborated an image digitalisation algorithm for use in estimating the tread's surface. Cybulska [40] also proposed her own methods for estimating yarn structure using digital image analysis. She carried out an assessment of the yarns' basic structural parameters such as thickness, hairiness, and twist, applying the image processing technique expanded by numerical methods. The method proposed enabled numerical structural characteristics to be obtained at every point of the yarn length, as well as acceptable average values and dispersion measures for the yarn's structural parameters.

The team directed by Krucińska [42] elaborated a digitisation algorithm for web estimation, where as Kopias, Mielicka and Stempień [43] used image digitisation to evaluate pneumatically-spliced polyurethane and textured yarns. For the image digitisation, they applied a method based on a scanner connected to a computer stand equipped with software programs designed for automatic object recognition. Abnormalities in the automatic image recognition process were eliminated manually.

The segmentation technique, which combines the level of preliminary image processing with the analysis of the particular objects' thresholds, is also used in computer image analysis. It enables the user to distinguish those image areas which fulfil the defined homogeneity criteria of the mask; this means distinguishing objects in the digitisation process which differ from the background. Krucińska & Graczyk [44], who measured the area of the fibres' surface, carried out a comparative analysis of selected segmentation methods based on the colour intensity gradient. Based on Materka's investigations [45], they measured the number of pixels which belonged to the given object, and next multiplied the number by the real pixel area. The analysis indicated that segmentation based on the intensity colour gradient of neighbouring pixels yields an almost identical result to manual segmentation. This results from the similar working principle of both the algorithms and the human mind, as a human who looks at an object initially distinguishes its boundary at places characterised by the greatest changes in colour intensity. The illumination also has a great influence on the quality of the digital image acquired. According to Kopias [43] and Jurasz [46, 47], while measuring the geometry of textiles, it is most advantageous to analyse images of flat structures obtained by illumination with reflected and transmitted light. Using optical systems with CCD transducers enables the best results to be obtained by image re-acquirement; deformations can occur only at the margins of the image mask. According to Tadeusiewicz & Korohoda [48], the image's non-linearity can be corrected by special software, which would (after the transducer) experimentally correct the coordinates, either using standards or by combining these both methods.

Considering the applications of digital image analysis so far used in textile science, and after carrying out a number of attempts ourselves, we have decided to develop our own variant of applying digital image analysis for estimating the parameters of spliced connections of yarn-ends. The procedure applied enables us to estimate the features of the external structure of the spliced connections at an unlimited length, together with numerical characteristics. Microphotos obtained as the result of the computer image analysis may serve for further research into estimating the quality of spliced yarn-ends, and enable quick recognition of the inappropriateness of the knot-free yarn connection process.

The aim of our investigations was to apply digital analysis for identifying the spliced connections of yarn-ends.

Materials and equipment

Combed wool yarn with a linear density of 25 tex and a twist number of Z630 was the object of our investigations. The yarn was spun with a Fiomax 2000 ring-spinning frame, made by Suessen. We focused only on identifying spliced yarn-end connections by selected digital image analysis techniques, although the identification procedure we present may also serve to identify other linear textile products, such as yarns, strings and ropes.

The process of winding, during which the spliced connections are formed, was carried out with an Espero automatic winder, made by Savio [51], equipped with a Jointair 4941 splicing device, made by Mesdan. This device was equipped with a 51W splicing chamber as well as Z20 preparing devices, designed for splicing combed wool yarn-ends. 50 images of spliced yarns were used for the analysis.

The splicing process may be conducted at different setting values of the splicing devices [7, 28]. For our investigations we used the settings recommended by Mesdan.

From the literature it results that up to the present, the qualitative evaluation of the spliced yarn-ends comes down to an analysis of the basic geometrical dimensions, organoleptic estimation of the connections, and assessing some strength properties [8, 28]. New methods of analysing spliced connections have been introduced during the investigations we present.

Research methods

An optoelectronic method based on the 2D digital image analysis was used for measuring the geometrical dimensions of spliced connections of yarn-ends. A plan of the measuring stand is presented in Figure 1.

The measuring stand shown in Figure 1 includes the following items; CCD Nikon camera from Panasonic, stereoscopic trinocular microscope used to connect a Steddy-T colour camera from CETI, a multimedia card which digitises the video image, and a computer set with the Microscan-1.5 software program [53].

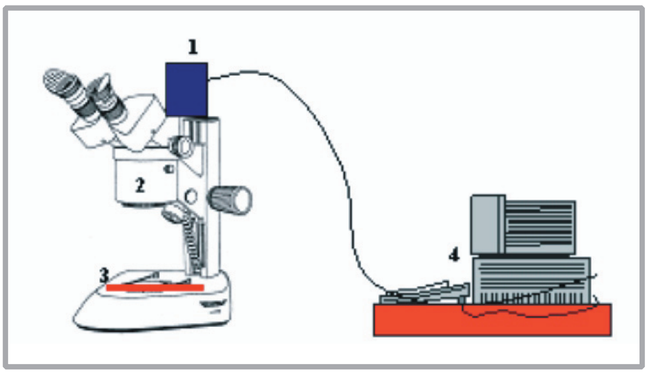

__Figure 1.__ Plan of the measuring stand used for analysis of images of spliced yarn-ends; 1 – video camera, 2 – stereoscopic microscope, 3 –yarn, 4 computer set.

The preliminary digital image analysis of the spliced yarn-ends by automated measurement activities within the MicroScan Video Viewer did not achieve positive results. Determining the proper measuring points into the structure of spliced yarn-ends was the essential obstruction to automating the activities. The automatic measurement comes down to obtaining a binary image and automated counting of the pixels of the object analysed. In order to change the full-colour image into a binary image, the threshold method is often used. This means that visible essential differences may be obtained for the particular objects, thanks to various thresholds while analysing the brightness level histogram. The precision obtained, while sharpening the image edges by manual setting the cursor, and the measurement itself, allow us to obtain greater objectivity and accuracy while carrying out measurements of the object's geometrical dimensions by appropriately determining the measuring points located at the edges of the object measured. Therefore, we decided to conduct image segmentation by the manual method, and to measure the geometrical dimensions manually as well.

Identification algorithm of spliced yarn-end connections by means of digital image analysis

The algorithm for determining the geometrical dimensions of spliced yarn-ends is presented in Figure 2.

Creation of a database of spliced yarn-end images

The images of yarns with joints recorded in 24-bit mode are characterised by good quality, but considering their structure, hairiness, and yarns' fluffiness, it would be troublesome to set the cursor at the appropriate measuring points, at the edges of the connection being analysed. Processing the digital image by applying suitable filters enables the image to be sharpened within the edge of the object being measured.

Digital image processing of spliced yarn-ends

Considering that the images obtained by the video camera were characterised by

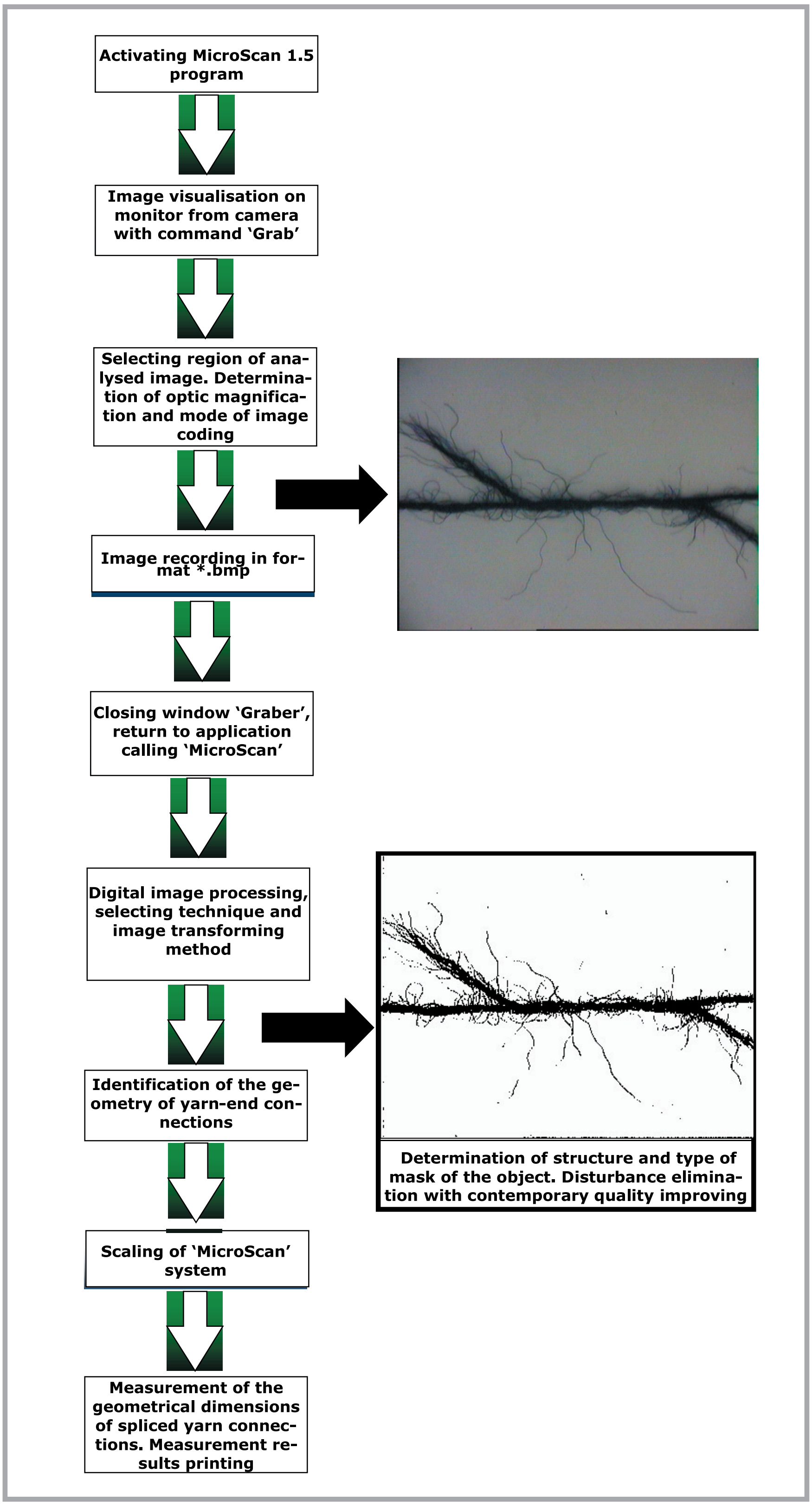

Figure 2. *Algorithm for determining the geometrical dimensions of spliced yarn-ends.*

differentiated levels of brightness, a need arose to balance these levels with the aim of unifying all the features of the objects' masks. A contrast adjustment was carried out by introducing a segment-linear function which broadened the range of colour brightness.

A levelling of the histogram was carried out, in order to secure a suitable quality of the object's image, together with its structural details. In many cases, the histogram unification should enable an image with structural details to be obtained, which would be more visible to a human eye than one obtained directly by the video camera, which is characterised by small brightness gradients. In our investigation, a procedure was used which describes the amount of points appearing in the area with a given grey-index of colour or a given colour component, R, G, and B. Furthermore, an automatic balance of grey levels was carried out, and the given object's mask was thus obtained with balanced shadows and semi-shadows. This effect was obtained by a pixel redistribution within the total tonal range. The result of the operation of balancing the brightness levels of the analysed image of the spliced yarn-end is presented in Figure 3.

Applying the procedure of balancing the grey levels of the object mask allows us clearly and objectively to compare the geometrical dimensions of the objects they cover, for all the images obtained.

The image of a spliced connection was also subjected to inversion of the brightness levels (Figure 4).

The level balancing was performed in order to draw the edges of the yarn connection more clearly. Thanks to this operation, the background was explicitly separated from the object (connection) identified. This also enabled the edges of

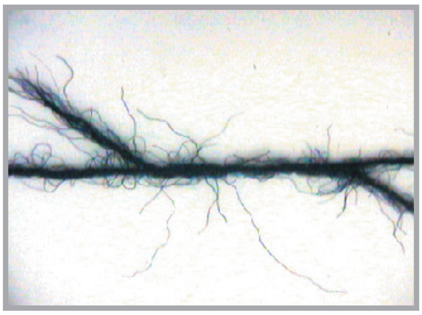

Figure 3. *Image after balancing the grey levels of the object mask.*

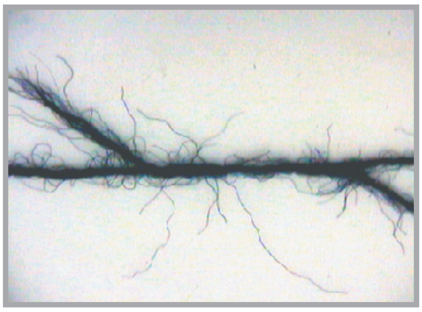

Figure 4. *Image after inversion of the brightness levels.*

the yarn connections analysed to be preliminarily determined. This significantly simplified the procedure of determining the threshold while analysing the brightness histogram.

After the contrast adjustment and brightness level inversion, the digital image obtained showed further visible disturbances in the background brightness level, which is to small distinguished from the object's brightness level. As the procedures used for image recognition are sensitive to this kind of disturbance, we decided to carry out an analysis and select the best from among the six filters available within the system which improve the object mask's quality. The MicroScan 1.5 system allows six kinds of filters to be used, which serve to distinguish the particular structural elements of the digital image. As a result of the analysis and many tests carried out, we concluded that the Laplace filter is the most advantageous for the identification of yarn-end connections. This is a high-pass filter which highlights the differences in brightness and colour of the mutually adjacent pixels, available in three types differentiated by the filtration mask and the filtration degree. The choice of mask ($[F_1]$, $[F_2]$, $[F_3]$) is made automatically. During operation with the Laplace filter, the following operators are used:

$$[F_1] = \begin{vmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{vmatrix},$$

$$[F_2] = \begin{vmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{vmatrix}, \qquad (1)$$

$$[F_3] = \begin{vmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{vmatrix}$$

Applying this method of image processing enabled us to distinguish areas fulfilling the determined criteria for the mask's homogeneity; this means that during the process of digitising the objects, they are distinguished from the background on which they appear. The images obtained were comparably significantly better after transforming the object mask by the Laplace filter, as the contrast and brightness mutually better resembled each other (Figure 5).

As a consequence, the double image thresholding could only be conducted more successfully in relation to the image processed by balancing the grey levels of the object mask and the level inversion.

The subsequent stage of identifying the yarn-end connections was to determine the structure and kind of the object's mass surface. In computer video systems, one of the more frequently used operations for image transformation is segmentation by thresholding. The aim of segmentation was to divide the image (according to a determined criterion) into uniform sub-areas, which were further identified and processed. This procedure facilitates suitable determination of the threshold by analysing the histogram, on the basis of which a decimal-to-binary conversion of images was performed. The binary images unambiguously enable us to determine the object's edges upon which the measurement is carried out; it is also important that the cursor can be placed objectively at the edges of the object analysed. As part of the scope of this research, we decided the measurements to carry out manually.

Image segmentation by the double HSY thresholding method was used for digital image analysis of the yarn-end connections. The image segmentation which was used enabled parameters to be obtained which were easier to interpret visually. As a result of the thresholding operation, a binary image was obtained in the memory; the background was white, and the selected objects black (0). This image is presented in Figure 6.

However, disturbances of the background's brightness level could be observed on the binary area obtained (Figure 6). Some image features used in the image recognition procedures are sensitive to this kind of disturbance. In order to prevent this trouble, one of the binary morphological operations, the closing operation, was used. Applying this operation enabled the disturbances at the level of the background's brightness from the image area after segmentation to be eliminated. The closing operation was carried out using a mask with its nucleus of dimension equal to three pixels. Using a greater mask-nucleus causes too great a separation of the areas of the object mask, which would hinder the image analysis. The final result of the closing operation is presented in Figure 7.

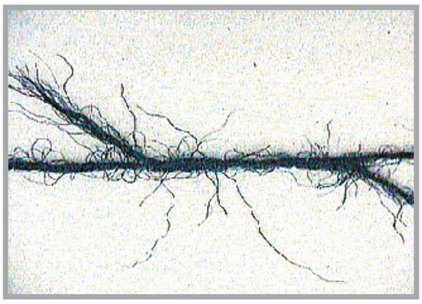

Figure 5. *Image after the Laplace transformation of the object mask.*

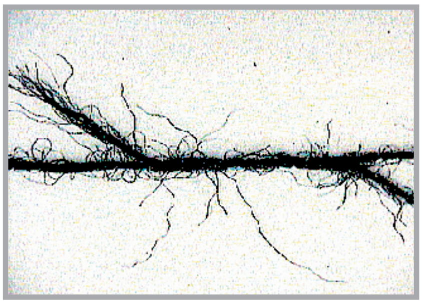

Figure 6. *Image after area segmentation of the object obtained as effect of thresholding.*

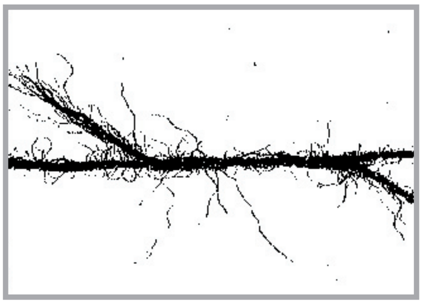

Figure 7. *Image after closing the object's mask.*

During the closing operation, the following operator was used:

$$[F] = \begin{vmatrix} 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 \end{vmatrix}. \qquad (2)$$

Measuring the geometry of the spliced connections of yarn-ends with the MicroScan 1.5 system

After determining the structure and kind of the object mask, the system and the resolution ability were scaled. To determine the image resolution ability related to the real dimension of one pixel [px], measurements of 1-mm segments of the standard objects (a microscopic slide and a millimetre-net of standard a microscopic slide) were carried out.

The choice of standard objects was caused by their high manufacturing accuracy, which enabled the standard's errors to be avoided. Investigations were conducted at a 20× magnification, and a series of 50 measurements of basic images into a dimensional uniform area was carried out. The main criterion, according to which the system of digital image analysis is estimated, is the image's quality at the system output; this is determined by such parameters of the object mask as resolution, sharpness, saturation, and contrast. Woźnicki broadly analysed the quantisation errors [29], which may be included in the group of the measuring device's errors. We deal with quantisation errors (Δx) while measuring by means of techniques which use the digital image transformation. According to [29], the quantisation error for the measurement method analysed is related to the value of ±0.5 of the real dimension of one pixel. Independently of quantisation errors, random errors of the average value also occur, which result from the dispersion of the feature tested [54]. The quantisation error is the error of the arithmetic average value of a series of measurements, calculated according to the following equation [56]:

$$\bar{x} - t\frac{S}{\sqrt{n}} < a < \bar{x} + t\frac{S}{\sqrt{n}} \qquad (3)$$

If the relative random error of the average value is known, the confidence interval for this value can be determined. The random error U of the average value depends on the accepted probability level, standard deviation, and number of measurements [56]:

$$\pm U = \frac{t \cdot S}{\sqrt{n}} \qquad (4)$$

where:
- t – the value of the t-Student's parameter determined for the number of independent variables $k = n - 1$, at the accepted significance level of $\alpha = 0.05$,
- S – the standard deviation, and
- n – the number of measurements.

On the basis of the measurements which resulted from the scaling by means of the MicroScan 1.5 system with the use of the microscopic slide and millimetre-net, the statistical parameters of scaling are listed in Table 1.

The small value of the relative random error of the average value εU of 0.6 signifies the high repeatability of the measurement results, and at the same the correct choice of the standard objects, the distinctiveness of the edges of the object measured, and the working efficiency of the measuring device. As a result of scanning the MicroScan 1.5 system, the real dimension of one pixel was:

$$R_{25Tex} = 1/14 \text{ mm/pixel}$$
$$= 0.0714 \text{ mm/pixel, and next}$$
$$1\text{mm} = 14 \text{ px} \pm 0.078.$$

The confidence interval for 1 mm of the standard objects is:

$$13.922 < 14 < 14.078$$

After scaling the MicroScan 1.5 system, the identification of the spliced yarn-ends was carried out.

The 'Arithmetic Operations' procedure was used for digitising the yarn-end images. This procedure enabled arithmetic and logic operations on the image. Thanks to this procedure, several operations are omitted, such as those connected with additional dimensioning and data recording, which over the further procedure would demand laborious calculations connected with quantity recounting. Dimensioning of one feature was limited to indicating, over one procedure, the particular points at the edge of the image analysed. Using this procedure allowed us to shorten the time needed to dimension the particular quantities of the image analysed.

While conducting the digital image analysis of the spliced yarn-ends, the dimensions of the objects identified were determined for each tested connection, on the basis of the operator identification (Figure 8):

Table 1. Average values of measurements of the standard objects: X_L - Average value, S - Standard deviation, CV - Coefficient of variation, εU - Random error of average value.

Parameter	kind of object	
	microscopic slide	millimetre-net
X_L, px	14	14
S, px	0.25	0.28
CV, %	1.76	2.01
U, px	0.07	0.08
εU, %	0.51	0.58

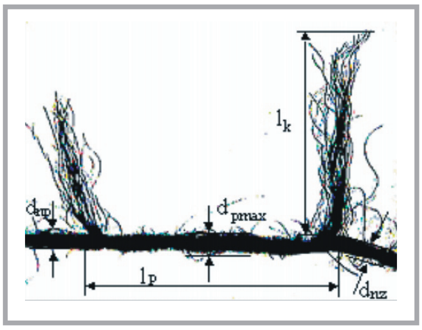

Figure 8. *Example of determining the geometrical dimensions of the yarn connection.*

length of connection l_{pi}, px - length of the joint structure of both yarn ends;
transversal yarn dimension at joint d_{ni}, calculated at average value

$$d_{ni} = \frac{d_{npi} + d_{nzi}}{2} \text{ in px,} \qquad (5)$$

where d_{npi} is the transversal dimension of the yarn in front of the connection, and t_{nzi} is the transversal dimension of yarn behind the connection;

- **maximum transversal yarn dimension at joint** – $d_{pmax\ i}$ in px,
- **coefficient of increase of the transversal dimension**:

$$\lambda_{di} = \left(\frac{d_{p\max i} - d_{ni}}{d_{ni}} \right) \text{ in px,} \qquad (6)$$

- **length of the longer, non-spliced yarn end** l_{ki}, px.

Table 2. Parameters characterising the yarn-end connection; symbols are given in Table 1.

Statistics / Procedure	X_L, px	X_L, mm	S, px	CV, %	U, px	εU, %
Length of connection, l_p = *"Max"*	249.48	17.82	73.08	29.29	21.10	8.54
Length of connection, d_n = *"Average"*	5.26	0.375	0.66	12.62	0.19	3.68
Maximum transversal yarn dimension at joint, d_{pmax} = *"Max"*	7.58	0.541	0.81	10.69	0.23	3.11
Coefficient of increase of the transversal dimension λ_D = *"Sub" And "Devide"* × 100	44.11%		23.05%	52.37	6.73%	15.28
length of the longest not spliced yarn end l_k = *"Max"*	102.48	7.32	45.64	44.62	13.3	13.08

It should be emphasised that in earlier investigations [14 - 28], the average length value of both yarn-ends, which were not spliced into the connection, was taken into consideration. However, the average lengths of the protruding yarn ends do not cause faults during subsequent technological processes, whereas only the longest ends create such faults. This was why we decided to measure the longest ends protruding off the connections. The parameters which characterised the connections we obtained are presented in Table 2.

Summary

Using image digitalisation and appropriate procedures allows us to obtain images which enable an analysis of yarn-end connections. Images suitable for analysis were obtained by using the following procedures:

- reduction of disturbances using the Laplace filter, and
- segmentation of the colour image by the HSY double thresholding method.

Furthermore, the operation of decimal-to-binary conversion enables us ti measure the geometrical dimensions of spliced yarn-ends at small measurement error values of the standard objects.

Conclusions

1. The algorithm proposed for digitising images of spliced yarn-end connections enables the precise identification of these connections, and the method of identification proposed permits an analysis of the geometrical dimensions at a level according to current set demands. It also enables the elimination of errors caused by improper settings, for example setting the scale-mark rule at the edge of the connection.
2. Applying digital analysis of the spliced yarn-ends' structure allowed us to significantly decrease the labour demand of the tests.
3. The digital analysis is not burdened by the large random errors which occur while using the traditional method of measuring the basic yarn parameters.
4. Suitably selected algorithms of the 2D-image analysis enable us to minimise the influence of random errors on the measurement results to a great degree.

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Received 10.10.2005 Reviewed 13.02.2006