Computer-aided image processing method for yarn hairiness evaluation

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Abstract: - Yarn hairiness is one of the most important parameter to be measured in textile industry, since it affects aesthetical and technical features of yarns and, consequently, of fabrics. Commercial devices for evaluating yarn hairiness are commercially available; these are characterized by a number of drawbacks such as high cost, considerable dimensions and weight. In order to overcome these limitations a number of works have been developed aiming to measure the hairiness by using image processing based methods. Most of these works propose a hairiness coefficient defined as the ratio between the total length of fibers protruding from the yarn body and a reference length. On the basis of these works, in the present paper a new methodology for yarn hairiness estimation based on a computer-aided image processing approach is presented. In particular, a simple acquisition system is proposed with the aim of determining a characteristic curve of the yarn hairiness and of defining an "equivalent yarn hairiness". The approach has been tested against the traditional Uster tester which is commonly accepted as one of the most important methods for measuring hairiness. Results show that the proposed method is suitable for the evaluation of yarn hairiness with an average error of about 7.5%.

Key-Words: - Computer-aided, Yarn hairiness, Image Processing, Machine Vision.

1 Introduction

Yarn hairiness measurement and control are key issues in textile industry since hairiness affects both the appearance of yarns (and fabrics) and other apparel parameters such as "hand", handle and thermal insurance [1]. Hairiness occurs when some fibers protrude from the yarn body or when some looped fibers arch out from the yarn core [2-3]. Accordingly, yarn hairiness may be defined as a measure of the amount of fibers protruding from the structure of the yarn [4]. Yarn hairiness assumes an impact which should not be underestimated by textile experts: high hairiness affects the efficiency of weaving and knitting processes due to a tendency to grip and fiber deposits on the machines. Moreover, it increases the probability of entanglements of adjacent ends possibly causing end breakage. On the other hand, high yarn hairiness (typically with hairs shorter than 3 mm) contributes to soft fabric hand that is preferred in many knitted fabrics [5].

Despite the huge number of studies on the field, most yarn hairiness determination methods are based on measuring the length and the number of the protruding fiber ends [6]. Among the commonly used equipment, the two most important are the Zweigle G565 hairiness tester and the Uster Tester 3 [7].

The Zweigle G565 tester simultaneously counts the number of hairs at certain distances by a set of photocells. Accordingly it provides the complete distribution of the different lengths of the hairs. In the Uster Tester an infra-red ray goes through a lens and falls on the yarn. The small size of the protruding fiber ends causes their diffraction and refraction which makes the light change its direction. The rays go through the lens assembly which directs them towards a photo-detector. Since the amount of the scattered light depends on the number and the length of fibers, the intensity of photo detector illumination is proportional to the total length of protruding fiber ends. The hairiness is, then, evaluated by means of a "Hairiness Coefficient" H defined as the ratio between the total length L_f of protruding fibers (mm) within a given length (mm) L of the yarn [8]:

$$H = \frac{L_f}{L} \tag{1}$$

Since the hairiness may considerably change along the linear development of a yarn, in the last years a number of works have been carried out in

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order to introduce more reliable and realistic indexes. For instance Guha et al. (2010) [9] presented a new method to measure the hairiness, based on the assumption that the hairs close and parallel to the yarn core would be a better indicator of hairiness, proposing a new parameter, the Hair Area Index. Recently, Carvalho et al. [10] introduced an image processing based technique for hairiness index evaluation in order to overcome a number of the main drawbacks identified in the traditional yarn testers (e.g. high cost, large volume, high weight, limited resolution and precision in the yarn mass parameters determination). Some of the authors of the present paper propose, in 2005, an automatic and non-intrusive tool to objectively monitoring the raising process by measuring the height and the density of the fibers emerging from a raised cloth. This work provides the definition of an equivalent height for fibers emerging from raised cloths. In the present work this kind of definition is extended to include yarn hairiness as explained in the following sections.

On the basis of these encouraging experiences, the main aim of the present work is to provide a new methodology for yarn hairiness estimation based on a computer-aided image processing approach. In particular, a simple acquisition system is devised in order to determine a characteristic curve of the yarn hairiness and to define a parameter called "equivalent yarn hairiness". The hairiness definition provided in this work considerably differs from the definition of coefficient H since, as detailed below, it is based on the principle of equivalency between the inspected yarn and an ideal one with all protruding fibers having the same height. A further difference resides in the fact that the proposed method is based on the inspection of a wide portion of the yarn, while other methods are applied to small portions, usually using a microscope.

2 Machine vision system

With the aim of defining a new parameter able to describe yarn hairiness, a machine-vision (MV) system was designed to perform the following tasks:
1) Image acquisition.
2) Image processing.
3) Processing of the numeric information provided by the image processing task and measuring of the yarn hairiness;
4) Equivalent yarn hairiness parameter definition.

2.1 Image acquisition

Yarn image acquisition is performed by using a commercial flat scanner with a resolution of 1200 x 2400 dpi. The scanner is connected to a PC by means of a graphical user interface (GUI), appositely developed in Matlab® environment, and the acquisition is performed by using an ActiveX Twain controller.

Yarn samples to be inspected are manually placed by an operator on the scanner and are, formerly, acquired. A simple algorithm has been developed in order to automatically scanning the area where the yarns are placed (see Fig. 1) and to crop an area equal to 210 x 50 mm. As a consequence, the resulting spatial resolution is equal to $\lambda = 0.175$ mm/pixel; this value may be considered sufficiently accurate for discriminating the yarn hairiness [11] in an approximate way.

Fig. 1 – Example of acquired yarn

2.2 Image processing

The devised image processing method relies on the following steps:

1) Image rotation by using a PCA based method.
2) Yarn diameter estimation.
3) Emerging fibers estimation.

2.2.1 Image rotation

Since the yarns are manually placed in the flat scanner, a preliminary rotation of the acquired image needs to be accomplished, as suggested in [10]. In the present work, the yarns are automatically rotated by evaluating their main axis using a Principal Component Analysis (PCA) based procedure. In fact, PCA is a multivariate method that analyzes a dataset in which observations are described by several inter-correlated quantitative dependent variables [12, 13]. Such a technique allows to extract the most relevant information from the dataset, to represent it as a set of new orthogonal variables called principal components, and to display the pattern of similarity of the observations and of the variables as points in a map. Given a blob of points (Fig. 2), PCA allows to determine, among other, the principal inertia axis, the centroid of the dataset (p_1 and p_2) and the angle α between p_1 and any other axes, conventionally chosen as the abscissa of a reference system.

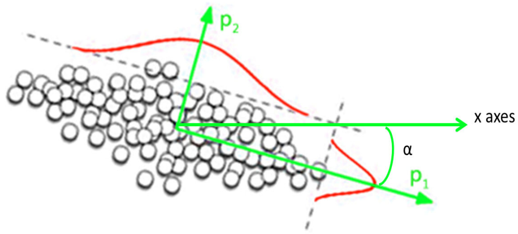

Fig. 2 – PCA-based determination of principal direction and determination of rotation α .

Let ***J*** be a digital raster image obtained by scanning a generic yarn. As widely known, the image is treated as a grid of discrete elements (pixels), ordered from top to bottom and left to right. Each pixel is, on its side, described by a triplet of values in the RGB color space or, possibly, by a single brightness value. In the first case, a simple transformation from RGB to gray scale image is, first, performed. The gray scaled image ***G*** is then thresholded by using the Otzu method [14].
The result of applying the threshold consists of a binary image ***B(i,j)*** (see Fig. 3) where the yarn is represented by white pixels (i.e. $b_{i,j}$ = 1) while the background is represented by black pixels (i.e. $b_{i,j}$ = 0).

Fig. 3 – Thresholded image ***B***

Since white pixels in image ***B*** represent a blob of points, it is possible to apply the PCA method to such an image in order to detect its two principal axis and the angle α .
Once p_1 is known, is it possible to rotate the image **J** by $-\alpha$ so as to obtain a rotated image **J'**.

In Fig 4 an example of PCA-based rotation of a generic, acquired, yarn is provided.

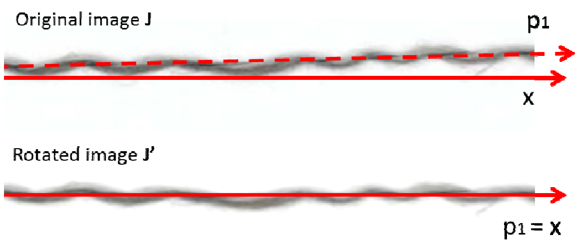

Fig. 4 – Image rotation.

2.2.2 Yarn diameter estimation

The main aim of the present work is to evaluate the yarn hairiness, it is mandatory to "remove" from the (generic) image **J'** the yarn so as to isolate the protruding fibers. As a consequence an estimation of the yarn diameter (D_y) taking into account possible yarn weaviness, is highly recommended. This has been carried out by using an appositely developed procedure, whose pseudo-code is described below.

Start
Threshold image **J'** with Otzu method, thus obtaining a binary image **B',** size nxm.
FOR each column *j* of image **B'(i,j)**
  K(j) = the set of all connected components in column j.
  k(*j*)∈K(j) = connected component intersecting p_1.
  h(*j*) = number of elements belonging to k(j) (i.e. local yarn diameters)
END
D_y = min(h(j)), where j = 1…m.
Stop

In Fig. 5, the described procedure is depicted with reference to a generic column.

In the provided example, two labeled component are detected (the green and the orange ones) by examining a generic column; the local yarn diameter is estimated equal to 10 pixels since the cluster k_2 contains the connected component intersecting p_1.

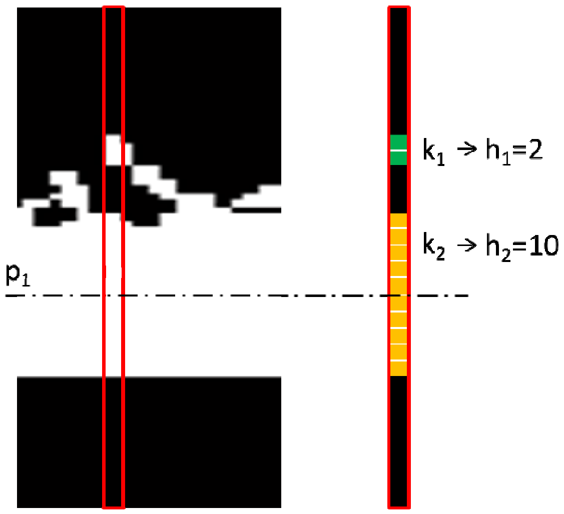

Fig. 5 – Local yarn diameter estimation.

The final result consists of a single value, for each yarn, of the estimated diameter (obtained as the min value of all the local diameters).

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In Fig. 6 the red lines represent the boundaries of a yarn identified by using the above described procedure; the white line represent the axes $p_1 = x$.

Fig. 6 –Yarn diameter estimation.

2.2.3 Emerging fibers detection

With the aim of achieving relevant information about the height of fibers emerging from the yarn body, these have to be purged by the yarn core itself. Accordingly, it is possible to define an image ***W*** (see Fig. 7) obtained by setting equal to 1 all the pixels in image ***B'*** bounded by the estimated yarn diameter (i.e., referring to example provided in Fig.6, the pixels between the two red lines).

Fig. 7 –Example of an Image ***W*** obtained by setting equal to 1 all the pixels bounded by the estimated yarn diameter.

Once ***W*** is evaluated, a two-dimensional Laplacian of Gaussian (LoG) filter can be used in order to detect the outlines of the emerging fibers in the images. As widely recognized, the output of the LoG operator (image L_W) depends on the value of the standard deviation (filter scale) σ. The value for σ is chosen on the basis of the dimension of the smallest particle to be detected by the LoG filter. In the present work a convolution mask with a filter scale $\sigma = 3$ [16] is used in the present work.

In Fig. 8, the effect of LoG filter on the generic image ***W*** is shown. In the background, the LoG filter smoothes the noise due to a not perfectly uniform background, and consequently, it does not find any zero crossing (also called transition) in such a region. Moving toward the fibers, a great number of zero crossings, correspondent to the outlines of the emerging fibers, are detected.

In other words, the LoG filter is able to detect the outlines of the emerging fibers, while the background (and, obviously, the core of the yarn) almost uniformly black.

Fig. 8 –Effect of LoG filter on a generic image **W**; the result consist of a binary image $\mathbf{L_W}$.

2.3 Processing of the numeric information provided by the image processing task and measuring of the yarn hairiness.

For each of the binary matrices L_W (i.e. for each LoG convoluted image), it is possible to evaluate, row by row, starting from the left upper corner, the number N_r of white pixels, i.e. the crossing of an edge produced by a single fiber thus obtaining the so called "characteristic curve" of a yarn.

In Fig. 9 an example of N_r is shown. Moving downwards from the upper side of the image, the algorithm detects more and more white pixels so that the curve begins to rise.

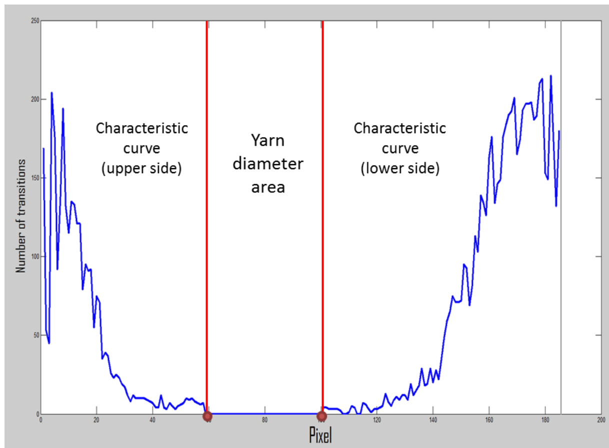

Fig. 9 –Characteristic curve.

This is due to the fact that the light diffusive region where the protruding fibers are situated has been reached. This behavior is preserved until a maximum value is attained. After such a value, the curve begins to decrease until the black region (i.e. the yarn core) is reached and the number of transitions, obviously, becomes again zero. Then, the curve begin to rise again since the opposite side of the yarn is reached (since the yarn is approximately cylindrical, if its weaving is neglected, the resulting characteristic curve results bi-modal).

The exemplificative curve shown in Fig. 9 contains all the relevant information about the height of the emerging fibers of the inspected yarn, as will be explained in the next section.

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2.4 Equivalent yarn hairiness parameter definition

On the basis of the characteristic curve explained above, it is possible to define a new parameter for yarn hairiness: the so called "equivalent yarn hairiness". This may be defined as the protruding fibres height Y_h of an ideal equivalent yarn, made of a number $\overline{N}$ of fibres, all having the same height.

Let Y_{hu} and Y_{hl} the distances along the abscissa, in the upper and lower sides of the yarn respectively, between the point c_u (or c_l, see Fig. 10) and the point s_{equ} (or s_{eql}):

$$Y_{hu} = \left| s_{equ} - c_u \right|$$
$$Y_{hl} = \left| s_{eql} - c_l \right| \quad (2)$$

where the points s_{equ} and s_{eql} are defined by the intersection of the vertical line separating the upper or lower characteristic curve in two equal area portions, and the abscissa axis (Fig.10).

According to its definition, the equivalent yarn hairiness Y_h is assumed to be equal to:

$$Y_h = \frac{Y_{hu} + Y_{hl}}{2} \text{ [pixel]} \quad (3)$$

The above provided equivalent yarn hairiness is expressed in pixels.

The same parameter in mm is obtainable by knowing the spatial resolution as follows:

$$Y_{h,[mm]} = \frac{25{,}4 \cdot Y_h}{\lambda} \qquad \text{[mm]} \quad (4)$$

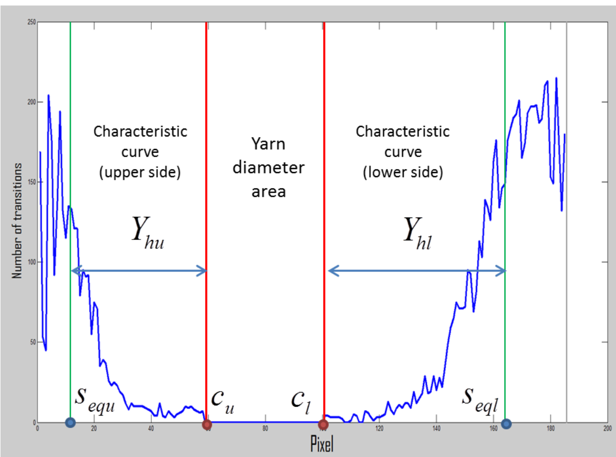

Fig. 10 –Equivalent yarn hairiness.

The parameter $Y_{h,[mm]}$ is the final results of the proposed methodology and it is assumed to reliably represent an estimation of the yarn hairiness.

3 Experimental results

The devised algorithm has been applied to a set of 4 wool samples with different yarn hairiness and diameter (see Fig. 11).

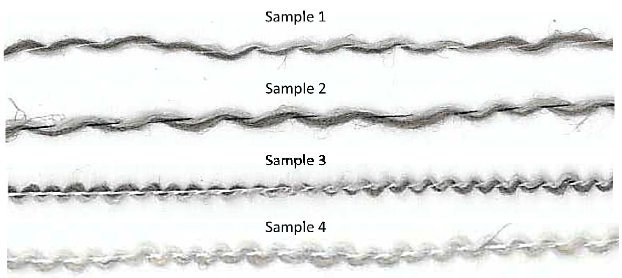

Fig. 11 –Samples of different yarns.

In order to validate the proposed approach the resulting equivalent yarn hairiness, evaluated by using Eq. 5, are compared against the results obtained using the standard Uster Tester.

In order to perform such a comparison it is necessary to derive from the equivalent yarn hairiness Y_h definition the hairiness coefficient H. This operation is not straightforward since the Y_h definition refers to (equivalent) fibres average height, while H is the total sum of all the fibres heights along a given length. As a consequence, it is necessary to evaluate $\overline{N}$ (i.e. the number of fibres composing the ideal equivalent yarn) in order to obtain an hairiness coefficient to be compared with the one measured using the Uster tester. In the present work $\overline{N}$ is evaluated by using the approach provided in [11] by using a dimensionless normalized pile density index ρ_{norm}, proportional to $\overline{N}$ itself. Therefore, the hairiness coefficient of sample yarns ($H_{compare}$) to be compared with the Uster tester one (H) may be evaluated modifying Eq. 1 as follows:

$$H_{compare} = \frac{\rho_{norm} \cdot Y_{h,[mm]}}{L} \quad (5)$$

Where L is set equal to 210 mm. In Table 1 the results of the comparison are listed and the percentage error is shown.

Table 1: experimental results.

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Sample	$Y_{h,[mm]}$	ρ_{norm} $(\times 10^{-3})$	H	$H_{compare}$	Error (%)
1	0.81	1.60	2.2	2.38	8.18%
2	0.96	1.27	3.4	3.59	5.59%
3	1.22	1.32	4.0	4.33	8.25%
4	1.31	1.37	4.2	4.51	7.38%

4 Conclusion

The present work proposed a computer-aided image processing method able to automatically and objectively evaluate the yarn hairiness by detecting a characteristic curve describing the behavior of yarn protruding fibers and by defining an equivalent yarn hairiness parameter.

The spatial resolution adopted for inspecting the yarns is lower than the one used in other works; accordingly the provided measurement has to be considered an approximation of the “real” hairiness of the yarn. On the other hand, the exam of a wider area allows to obtain a more robust measurement with respect to the one obtainable by examining small yarn portions.

Results show that the proposed method proves to be suitable and effective for evaluating yarn hairiness within an average error of about 7.5% with respect to the Uster tester. In particular, with the approach described in Section 2 it is possible to measure with a nonintrusive technique an equivalent yarn hairiness to be correlated to the hairiness coefficient. Future works will be related (1) to the development of a statistical approach aiming at a better definition of the equivalent yarn hairiness, (2) to a better definition of the yarn fibers density and (3) to carrying out a more extensive experimental campaign.

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