**Proceedings of the Ninth IASTED International Conference**
**CONTROL AND APPLICATIONS**
**May 30–June 1, 2007, Montreal, Quebec, Canada**
**ISBN Hardcopy: 978-0-88986-665-2 / CD: 978-0-88986-666-9**

# OPTICAL QUANTIFICATION OF YARN HAIRINESS USING PROJECTIONS ALONG A SINGLE DIRECTION

Vítor CARVALHO[1], Paulo CARDOSO[2], Michael BELSLEY[3], Rosa M. VASCONCELOS[4]
and Filomena O. SOARES[5]

[1,5]DEI, UM, Azurém, Guimarães, Portugal, e-mail: (vcarvalho[1], fsoares[5]) @dei.uminho.pt
[2,3]DF, UM, Gualtar, Braga, Portugal, email: (pjcardoso[2], belsley[3]) @fisica.uminho.pt
[4]DET, UM, Azurém, Guimarães, Portugal, e-mail: rosa@det.uminho.pt

## ABSTRACT

This paper presents a system which is able to measure yarn hairiness using coherent optical signal processing, plus the associated electronics and custom software. By placing a spatial high-pass optical filter in the Fourier plane, to remove the low spatial frequency information (yarn core and light that does not hit the yarn). High spatial frequencies, which correspond to hairiness and the yarn borders, are transmitted. To quantify hairiness, a photodiode, plus a trans-impedance amplifier were used to obtain a voltage proportional to the hairiness signal. A data acquisition system controlled by an application developed in LabVIEW is used to acquire and process the measured data. However, an open question remains as to whether one can obtain a valid characterization of the yarn properties using a single projection direction. The results reported here demonstrate that in the case that the hairiness is randomly orientated a single projection measures on average 0.64 of the hairiness present on the yarn.

**KEY WORDS**
Process Optimization, Yarn Hairiness, Signal Processing, Optical Sensors

## 1. Introduction

Hairiness is an important parameter when characterizing yarn quality in the textile industry. It consists of small fibers that protrude from the main yarn core as shown in figure 1.

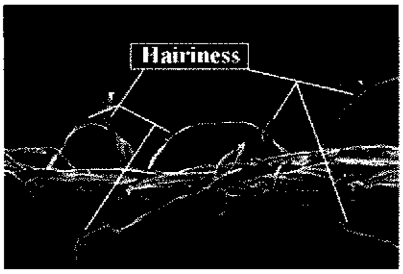

Figure 1. Electron microscope photograph of yarn hairiness

To measure yarn hairiness we employ an optical and an electronic setup. Figure 2 presents the optical hardware [1-6].

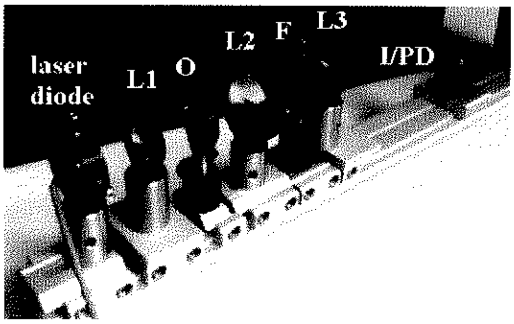

Figure 2. Custom developed optical yarn measurement hardware

The objective of the optical setup is to obtain a signal proportional to the degree of yarn hairiness in the final image plane (position of the photodiode in Fig. 2) (I/PD). Coherent light from the laser diode is incident on a beam expander lens (L1) and is directed to the yarn, placed in the object holder (O). The size of the object image is controlled by the lenses L2 and L3.

A custom fabricated spatial filter (F) is placed in the Fourier plane of L2, to process the image, permitting only the high spatial frequencies in the image to propagate further (high pass spatial Fourier filter) [7-10]. This results in the contours of the edges of the yarn and associated hairs being highlighted while simultaneously eliminating the constant background.

Figure 3 presents an example of an image obtained with the optical setup.

Figure 3. Example of an image obtained with the optical setup

Figure 4 presents the developed the electronic instrumentation hardware.

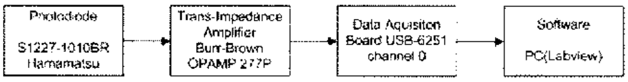

Figure 4. Custom developed electronic yarn measurement hardware

The objective of the electronic hardware is to obtain a voltage proportional to the brightness of the final image. The output of a trans-impedance amplifier connected to the photodiode is read by a Data Acquisition Board (DAQ). Previous studies have confirmed that using this setup, the output voltage is proportional to the hairiness length [3]. Also a statistical method to obtain the reference (without hairiness) was also developed [4].

The system measures the hairiness using a single projection onto the plane perpendicular to the direction of incident light. A full 360° rotation of a sample of yarn containing one single hair oriented perpendicular to the yarn core using this system results in a signal similar to that plotted in figure 5, which is the absolute value of the cosine.

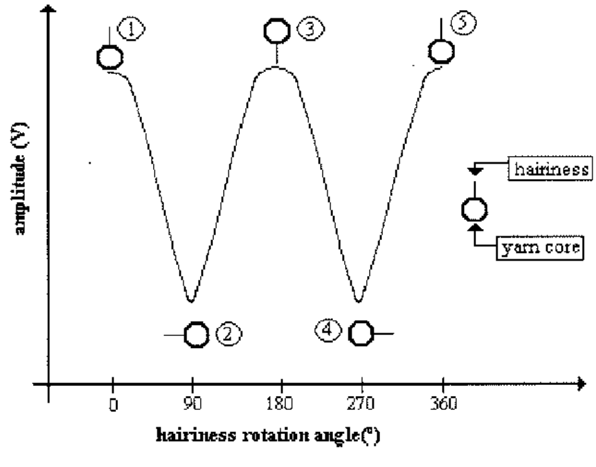

Figure 5. Example of the signal resulting from a 360 ° projection of one hair, using a single photodiode

Assuming that the laser light is incident from the left along the horizontal direction and considering a top view, the maximum signal is obtained for positions referenced by 1, 3 and 5, which corresponds to situations where the maximum hair length is projected into the photodiode. On the other hand, the minimum signal is obtained for positions referenced by 2, 3 and 4, which correspond to situations where the hair is not projected into the photodiode.

If several hairs were positioned over the yarn with angular displacements, several protruding deviations will be obtained from the absolute value of the cosine.

The average signal obtained using a single projection corresponds to roughly 2/π times the maximum signal that would be obtained if the hair were found to lie completely in the projection plane, as shown by the following integral,

$$Sf_1 = \frac{1}{2\pi}\int_0^{2\pi}|\cos(\theta)|d\theta = \frac{2}{\pi} \approx 0.64 \tag{1}$$

So, the total hairiness, ($S_t$), would be in fact π/2 times greater than the average amount of hairiness ($Sf_1$), referenced to obtained using a single projection,

$$S_t = \frac{1}{Sf_1} = \frac{\pi}{2} \approx 1.57 \tag{2}$$

## 2. Experimental Results

To analyse the results obtained for hairiness in a full projection analysis (360°) using a single photodiode, several samples of four different yarns. In each case the same yarn was sampled at 8 or ten different locations, while at each sample location the yarn was rotated by 360 degrees.

Table I presents the linear mass and corresponding diameter for each yarn tested.

TABLE I
Description of yarns used in the test

| Samples | Yarn linear mass (g/km) | Yarn diameter (mm) |
|---|---|---|
| 0 | 295.0 | 0.64 |
| 1 | 62.0 | 0.29 |
| 2 | 49.2 | 0.26 |
| 3 | 4.2 | 0.08 |

Figure 6 presents the standard deviation (SD) of the results obtained for each yarn sample over a full 360° rotation. Figure 7, shows the SD over average ( of figure 5 for each yarn.

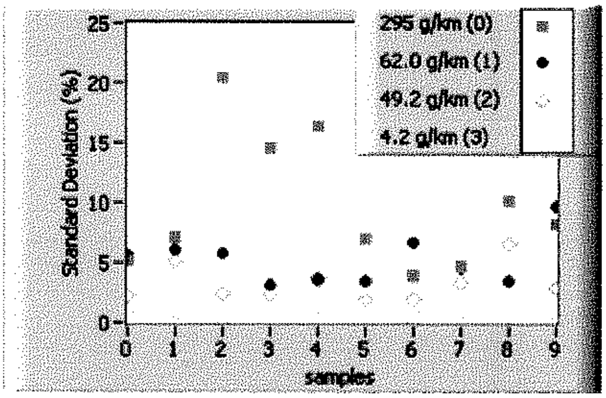

Figure 6. Standard deviation results for the tested yarn samples over a 360 ° analysis

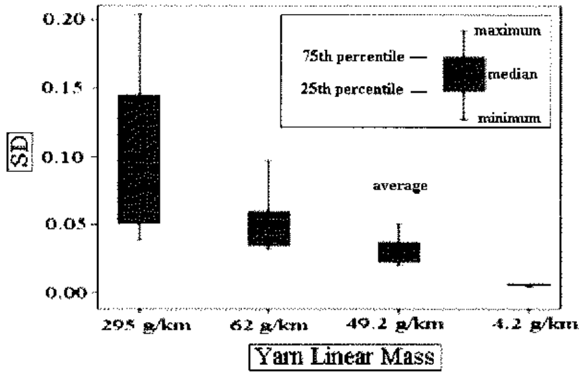

Figure 7. Standard deviation results over average for each analyzed yarn

From figures 6 and 7 it is clear that, between yarns, the amplitude of the standard deviation (SD), is, in general, strongly correlated to the level of hairiness of each yarn (the higher the level of the hairiness coefficient, the higher the SD). For these yarns the hairiness level is also strongly correlated to the linear mass of the yarn; the 4.2 g/km yarn is the least hairy [11] while the 295 g/km is the most hairy [5]. Correspondingly, the lowest SD amplitude was obtained for the 4.2 g/km yarn followed by the 49.2 g/km and 62 g/km yarns. The highest SD amplitude is obtained for the 295 g/km yarn. This situation can be explained by the fact that a higher linear mass yarn has more fibers per unit length and subsequently a higher probability of releasing fibers, which results in a higher hairiness coefficient.

To understand what produces higher standard deviation results at some of the yarn locations sampled, the full 360 degree projection signal of samples: 2 and 3 of yarn 295 g/km, sample 9 of yarn 62 g/km and sample 4 of yarn 49.2 g/km, are presented by figures 8 to 11, respectively.

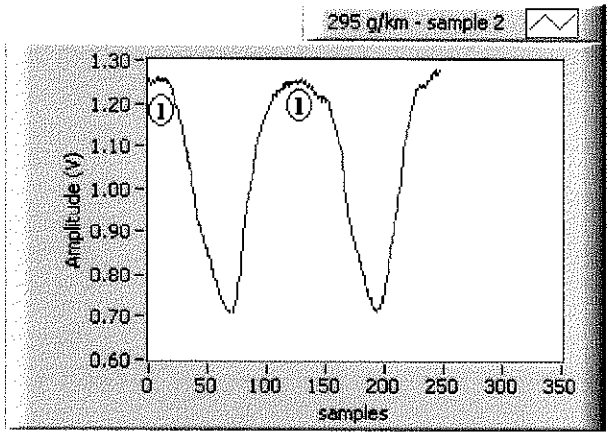

Figure 8. Signal projection of sample 2 of the 295 g/km yarn

Figure 8 suggests that sample 2 of the 295 g/km yarn has a clearly distinguished and relatively long hair, because only one spike is obtained over the yarn rotation. This causes a signal variation of 0.70 V to 1.25 V, which leads to a SD of about 21%, which is the highest for this yarn.

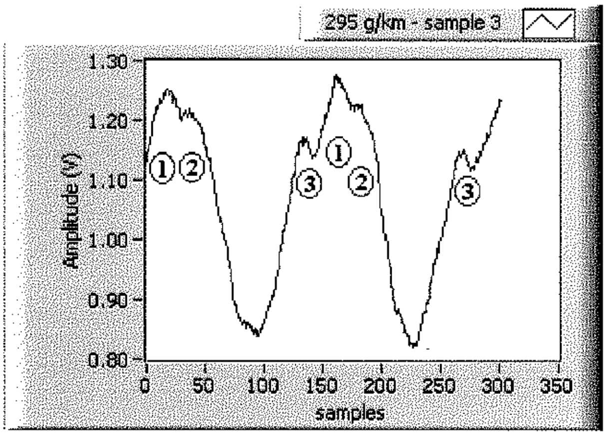

Figure 9. Signal projection of sample 3 f the 295 g/km yarn

In figure 9 three spikes are clearly visible over the rotation. This suggests that sample 3 of the 295g/km yarn has either three clearly distinguished hairs or a hair with a rather twisted geometry, This results in a signal variation of 0.85 V to 1.25 V, which leads to a SD of about 14%, somewhat lower than that of figure 8. The minimum is also somewhat higher in figure 9, suggesting some hairiness was always visible in the projection taken by the incident light regardless of the orientation. Overall however, the signal contours of this sample are rather similar to those of figure 8, and both yield averages close to 1 V. Thus even though the standard deviation is roughly 50% higher for the figure 8, on average both samples have approximately the same hairiness value.

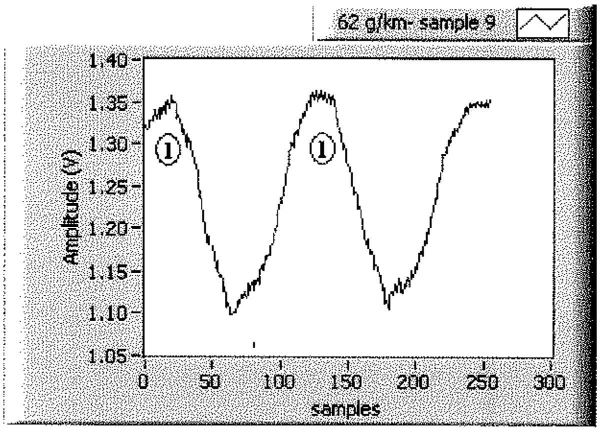

Figure 10. Signal projection of sample 9 of the 62 g/km yarn

Looking at figure 10, it appears at first glance that this sample has, as that of figure 8, has one clearly distinguished hair, because only one spike is obtained over the rotation. This causes a signal variation from 1.10 V to 1.35 V, which leads to a SD of about 10%, which is also the highest for this yarn. However the minimum is a little less sharp, suggesting that there maybe several small hairs close to the yarn core. Comparing this signal to the signal of figure 8, it is possible to state that the lone dominant hair length of this sample is inferior, due to the lower SD. However, the average signal is higher (around 1.22 V) supporting the hypothesis that there are several small hairs more or less evenly distributed about the core for this sample location.

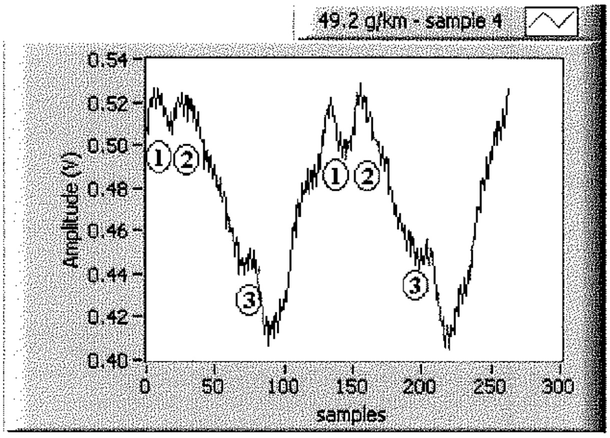

Figure 11. Signal projection of sample 4 o f the 49.2 g/km yarn

Figure 11 shows a sample with three clearly defined peaks similar to the situation of figure 9. As for figure 9 this could be due to three distinct hairs or fewer hairs with a more complicated geometry. This causes a variation of the signal around 0.41 V and 0.52 V, which lead to a SD of about 3%, which is one of the highest of this yarn. Comparing this signal to the signals of the previous projection figures, is possible to state that the total hair length of this sample is quite a bit less, due to the much lower SD. Moreover, the average signal is also quite a bit lower being around 0.46 V.

Figures 8 to 11 confirmed that high SD results are associated with high hairiness levels.

Figure 12 presents the case of a low SD result for sample 6 of the 4.2 g/km yarn.

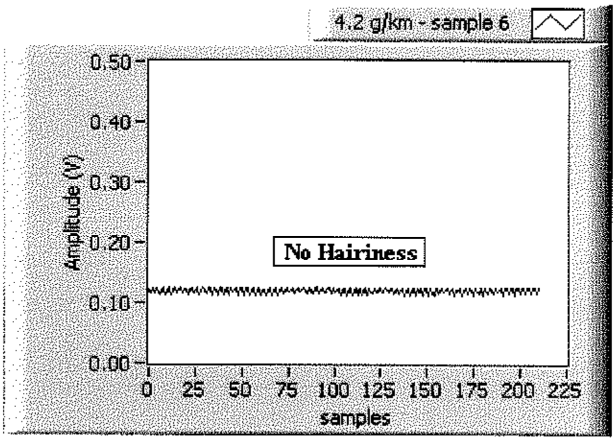

Figure 12. Signal projection of sample 6 o f 4.2 g/km yarn

Figure 12 shows a situation where no hairiness is present. This is stated due to the practical constant signal obtained, with a very low SD, around 1%. As one would expect for the lowest mass yarn without hairiness, the average signal is also extremely low (around 0.12 V). In fact it is the lowest average signal of all the samples presented.

Analyzing figures 8 to 12 it is also verified that the presented signals are repeated every 180°, as expected. This permits us to claim that the measurements carried out have good reproducibility. The small variations, between signals separated by 180° are related to the small possible oscillations of the yarn as it was being rotated or more probably because the rotation was performed manually and consequently the rotational speed was not exactly constant.

Figure 13 presents possible hairiness geometries for the analyzed samples (Fig. 8 to Fig. 12). However, as mentioned above, more complicated configurations could are possible with the hairs curling in three dimensions around the yarn core.

Figure 13 portrays the yarn linear mass (yarn diameter), represented by a variable radius circle as the yarn core, in addition to the hairiness position (angle displacement) and length. In each sample the hair number indices are related to those represented in figures 8 to 12.

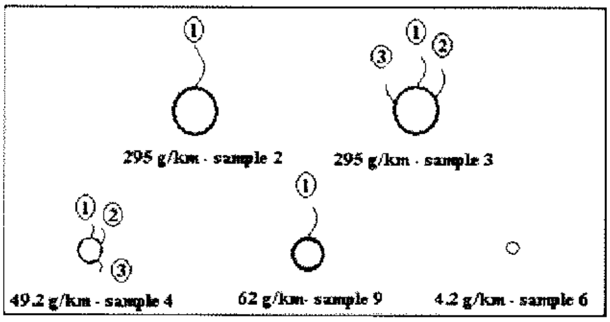

Figure 13. Possible hairiness geometries, for each of the samples analyzed in figures 8-12.

One of the problems associated with analyzing yarn hairiness using one single projection is the level of confidence one can have as to whether the overall level of hairiness, is correctly characterized. To answer this question, 6 meters of yarn, at a sample frequency length of 1mm were analyzed with one projection. This procedure was performed for all the yarns and the final SD were determined [4].

Figure 14 presents the SD of the results, obtained for the variation of the each sample of each yarn, in relation to the average SD for samples over a full 360 ° rotation. Moreover, it also shows the SD results, in relation to the average, obtained using a single projection at 6000 sample locations for each yarn.

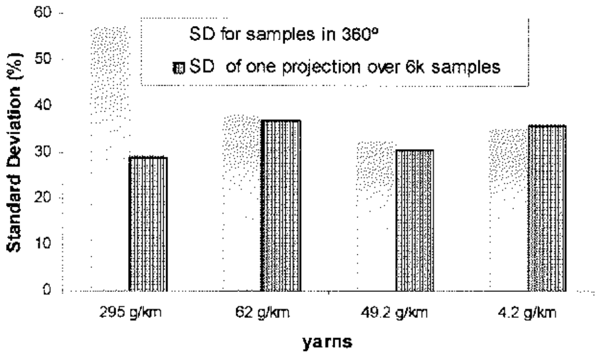

Figure 14. SD comparison between samples in a 360° full rotation and 6000 samples at one direction

As expected, in figure 14, for the yarns with lower values of hairiness (the 62, 49.2 and 4.2 g/km yarns), the single projection values agree closely with the SD obtained using 360° rotation, even though only 10 locations were sampled in the 360° case (in fact only eight were carried out for the 4.2 g/km yarn). However, for the most hairy yarn (295 g/km), a clear difference is visible. In this particular situation, due to the higher dispersion of hairiness, a reduced number of samples are not sufficient for a correct characterization of the yarn. We are convinced that by increasing the number of locations sampled using the 360° rotation, the values will approximate more closely the SD level of the 6000 locations sampled using a single projection for this yarn.

After achieving a pattern result, every 180°, in a full angular projection, we needed to test if the hairiness is in fact randomly distributed over the yarn. To test this parameter, we first need to know the necessary amount of yarn length (number of samples) required to assure good statistics. To perform this experiment, we made an analysis of the yarn, with higher level of hairiness (295 g/km), which was the less favorable case. Consequently, as the SD is the maximum level of the tested yarns, the number of samples required should be the higher. So, we performed a measurement of this yarn, over 24 meters, sampling every millimeter. This resulted in 24000 total samples, for which we kept up a running calculation of the average and standard deviation of the signal. Figure 15 presents the evolution of the SD of yarn 295 g/km for 24 meters.

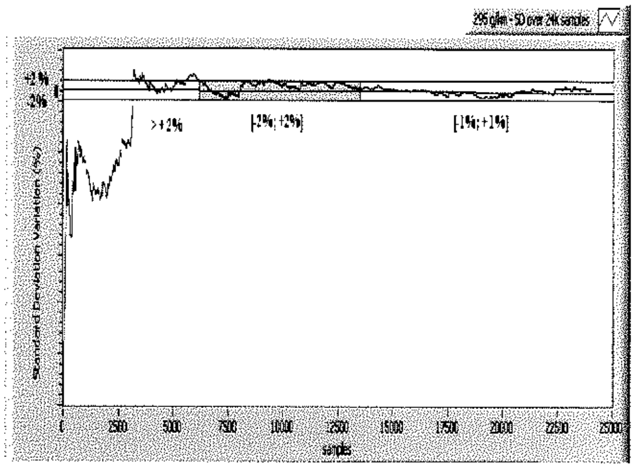

Figure 15. Evolution of the standard deviation results obtained for the 295 g/km yarn over 24 meters

Figure 15 presents a SD variation over the average, superior to 2% between 3 and 6 meters, in the range [-2%; 2%], between 6 meters and 14 meters, and in the range [-1%; 1%], in lengths superior to 14 meters. A SD variation around ±1% can be considered reasonably stable and a sample analysis of 24 meters is certainly enough to correctly characterize the level of hairiness of yarns. This is true even for those with high levels of hairiness coefficient, as the one tested.

After validating the required length of yarn to correctly verify if a hairiness distribution pattern is present, we compressed the acquisition signal, for an easier analysis.

Figure 16 present the compressed acquisition signal, in bands, for 24 meters of yarn 295 g/km.

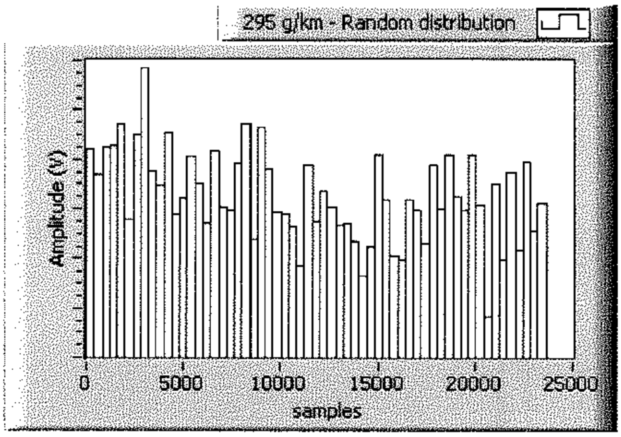

Figure 16. Compressed acquisition signal of yarn 295 g/km over 24 meters for pattern recognition

Analyzing carefully figure 16, there does not appear to be present any obvious signal pattern. Instead the hairiness levels appear to be quite randomly distributed. In this case, a valid probability of equal hairiness distribution, around 360° over each yarn sample could be considered, for the number of samples used in a test. Subsequently, as mentioned above in section I, multiplying the results of a single projection by a factor of 1.57 should give the proper value for the total hairiness of the sample in three dimensions.

## 3. Conclusion and Future Work

We have shown that when a single straight hair is present the signal obtained by rotating the yarn over 360 degrees varies likes the absolute value of the cosine with a periodicity of 180 degrees. This allows one to use a single projection to adequately characterize samples with randomly distributed hairiness – one simply needs to correct the single projection results by the factor of $\pi/2$ which takes into account the average projection seen by the system.

A sample length of 24 meters was determined as enough to correctly characterize yarn hairiness, as the test was realized for the higher SD yarn (295 g/km), which was the worst case. Even, after 14 meters of samples, the SD had a variation over ± 1%, which could be considered stable. In practise the running average and standard deviation can be simultaneously with the acquired signal allowing one to conveniently determine the necessary sample length in each separate case.

No pattern distribution was verified for hairiness, it appears to be randomly distributed over the yarn. This fact, associated to the 180° signal pattern, of hairiness, during a 360 ° for one projection, lead us to affirm that the final hairiness value, is well approximated by $\pi/2$ times the value obtained using a single projection. So, with only one photodiode, we are able to quantify, with confidence, the total amount of hairiness of a yarn.

Furthermore, the applied coherent optical signal processing, is a reliable methodology to measure yarn hairiness, as a result of its proper and reproducible results. So, with the developed system, we are able to measure correctly several statistical hairiness parameters, such as H, sH, UH, CVH, DRH, IDRH [11], between others, and using signal processing techniques (FDFI, FWHT e FFT) [11-13] to determine hairiness error patterns.
Future work will focus on obtaining experimental proof that using only one projection, a reliable yarn hairiness characterization, can be performed. This test, should considerer two photodiodes oriented along orthogonal directions. After a considerable number of samples, the result obtained for one projection should be well correlated with the sum of results of the two photodiodes.

## Acknowledgements

The authors are grateful to the Portuguese Foundation (FCT) for funding through the scholarship (BD/ 19028/ 2004).

## References

[1] V. Carvalho, P. Cardoso, M. Belsley, R. Vasconcelos and F. Soares, "Determination of Yarn Hairiness Usign Optical Sensors", *EUROSENSORS XX*, 17-19 September, *Gothenburg, Sweden*, 2006.
[2] V. Carvalho, P. Cardoso, M. Belsley, R. Vasconcelos and F. Soares, "Development of a Yarn Evenness Measurement and Hairiness Analysis System", *IECON06*, 7-10 November, *Paris, France*, 2006.
[3] V. Carvalho, P. Cardoso, M. Belsley, R. Vasconcelos and F. Soares, "Yarn Hairiness Parameterization Using a Coherent Signal Processing Technique" (accepted for publication in Sensors and Actuators).
[4] V. Carvalho, P. Cardoso, M. Belsley, R. Vasconcelos and F. Soares, "A New Statistical Reference Method for Yarn Hairiness Quantification" (submitted for publication in ISIE 2007).
[5] V. Carvalho, M. Belsley, R. Vasconcelos and F. Soares, "Yarn Hairiness Characterization based on optical signal processing" (submitted for publication in Transducers '07).
[6] M. Silva, *Medida do Paralelismo de Fibras – Índice de Eficiência de uma Máquina*, PhD Thesis, University of Beira Interior, Vila Real, Portugal, 1983.
[7] J.W. Goodman, *Introduction to Fourier Optics*, McGraw-Hill, Greenwood Village, 1996.
[8] E.G. Steward, *Fourier Optics: An Introduction*, Dover Publications, New York, 2004.
[9] P.M. Duffieux, *The Fourier Transform and its Applications to Optics*, 2nd Edition, John Wiley & Sons, New York, 1983.

[10] C.K. Madsen, *Optical Filter Design and Analysis: A Signal Processing Approach*, Wiley-Interscience, New York: 1999.

[11] V. Carvalho, M. Belsley, R. Vasconcelos and F. Soares, "Yarn Hairiness Optical Measurement System" (submitted for publication in INDIN '07).

[12] V. Carvalho, *Parametrização de Fio Têxtil Baseada na Análise de Massa.*, Msc Thesis, Minho University, Guimarães, Portugal, 2002.

[13] J.L. Monteiro and C. Couto, "Pulse frequency calculation and estimation in yarn evenness analysis ", *IEEE Industrial Electronics Society, Orland, USA*, 995.