Automatic Yarn Characterization System

*Vítor Carvalho and Filomena Soares
Dept. of Industrial Electronics
Minho University
Guimarães, Portugal
*vcarvalho@dei.uminho.pt, fsoares@dei.uminho.pt

+Michael Belsley and Rosa M. Vasconcelos
+Dept. of Physics, Dept. of Textile Engineering
Minho University
+Braga, Guimarães, Portugal
+belsley@fisica.uminho.pt, rosa@det.uminho.pt

Abstract—**This paper presents an innovative, low cost, portable and high-precision yarn evaluation tester, YSQ (Yarn System Quality), for quality control of yarn characteristics under laboratory conditions. It presents a modular format, which can integrate simultaneously yarn hairiness, mass, regularity and diameter measurements. The quantification of yarn hairiness and diameter variation (with a sampling resolution length of 1 mm) is carried out using photodiodes; the diameter characterization, based on 0.5 mm width samples, employs a linear photodiode array; the measurements of mass variation, based on samples of 1 mm, employs a parallel plates capacitive sensor. In the YSQ measurement parameters based on optical sensors, a coherent signal processing technique with Fourier analysis is used, to obtain linear and consistent output signal variations. A comparison between results obtained using the YSQ and a commercially available solution is presented.**

I. Introduction

The correct and accurate evaluation of yarns is a subject of major importance to the Textile Industry, as the final fabric quality depends directly on the yarn quality. To undertake these yarn tests several firms have developed specific equipments. The Tester 5 from *Uster* [1] and the Multitester from *Zweigle* [2] are notable for their relevant contributions to the development of quantitative yarn characterization. However, these equipments have a significant cost, require a considerable area for their installation and present limited resolution and precision in the evaluation of certain yarn parameters. As a result, some yarn producers do not have their own yarn testers and, instead, choosing to subcontract dedicated testing laboratories. This process is time consuming and eliminates the possibly of acting in useful time during yarn production, reducing efficiency.

II. YSQ Sensors System

This section describes the optical and electronic setups considered to obtain the measurements of yarn hairiness, yarn diameter and mass variation [3-6].

A. Three Directions Optical Configuration

In order to reduce the YSQ volume and cost, only one diode laser source was employed (Eudyna FLD6A2TK [7]) to establish three different beams. This single source was divided in three beams using two beam splitters (first beam splitter division 50 % / 50 %, second beam splitter division ≈ 3 % / 97 %). The final configuration of the optical measurement setup considers three different directions placed in three different arms. Fig. 1 presents the YSQ optical setup employed where, Src is the diode laser source that emits light at 685 ± 10 nm in both single transverse and single longitudinal modes, with a low aspect ratio of 1.3, HPF represent a high-pass spatial filter, LPF is a low-pass spatial filter, FL is the Fourier lens, B1 is the first beam splitter, B2 is the second beam splitter and L1 to L4 are plano-convex lens.

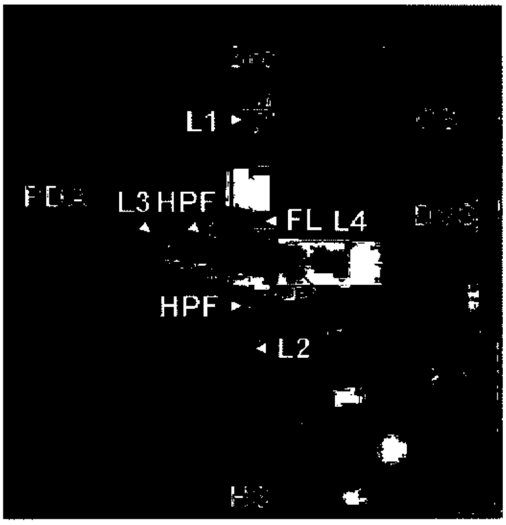

Figure 1. System optical configuration

Observing Fig. 1 one can see that the beam splitters were placed immediately after the Fourier lens. As in this case there are two different types of spatial filters (high-pass filters, HPF and low-pass filters, LPF), the beam division should be performed before the signal filtering to allow the application of different filters. The first beam splitter (B1) makes an equal signal division whereas the second beam splitter (B2) directs only 3 % of the signal for the left arm. These choices are taken because the yarn contours and hairiness require stronger signal intensity, as the majority of the signal component is filtered by the high-pass filter [8]. However, the yarn core and light which is not blocked by the high-pass filter do not require high signal intensity, since only the contours and hairiness are filtered by the low-pass filter maintaining the strongest signal components [9]. Fig. 2 presents an image obtained in the image plane of lenses L2 (HS-Hairiness Sensor) and L3 (PDA-Photodiode Array), where only the yarn contours and hairiness are observed (the yarn core and light which is not blocked by the yarn were eliminated).

Figure 2. Image plane of lenses L2 and L3

Fig. 3 presents an image obtained in the image plane of lens L4 (DVS-Diameter Variation Sensor), where it only a shadow of the yarn core and light which is not blocked by the yarn are observed (the yarn contours and hairiness were eliminated).

Figure 3. Image plane of lens L4

B. *Electronics Configuration*

The images obtained in the image plane of lenses L2 (HS) and L4 (DVS) are aquired by two equal configurations of the developed electronic yarn measurement hardware shown in Fig. 4 [8, 9].

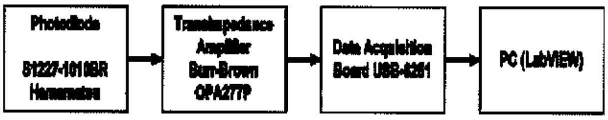

Figure 4. Custom developed electronic yarn measurement hardware for the HS and DVS

In Fig. 4, a photodiode (S1227-1010BR) from Hamamatsu [10] was chosen as a receiver. It is a low cost photodiode, with a high sensitivity for red wavelengths (for the laser used, 0.39 A/W), a large active measurement area (10 mm x 10 mm), a low dark current (maximum of 50 pA), a high shunt resistance (2 GΩ), a noise equivalent power (NEP) of 3.1 x10^{-15} W/$Hz^{1/2}$ and a low terminal capacitance (3000 pF). It includes a current to voltage converter (transimpedance amplifier) connected to an analogue channel of the data acquisition board. Software developed in LabVIEW® from National Instruments [11] was used to acquire and process the data.

In order to allow a yarn sampling resolution length of 1 mm, an opaque window was placed in front of the photodiodes with a width (mm) equal to the amplification factors obtained in these directions (1.11 and 1.15, respectively to the HS and the DVS).

The measurement of precise yarn diameter (PDA) was based on line profile analysis [12]. Fig. 5 presents the line profile analysis indicated in Fig. 2 for 512 pixels, where the red plane intensity line profile signal, is proportional to the voltage signal resulting from the hairiness distribution image of the linear array photodiodes.

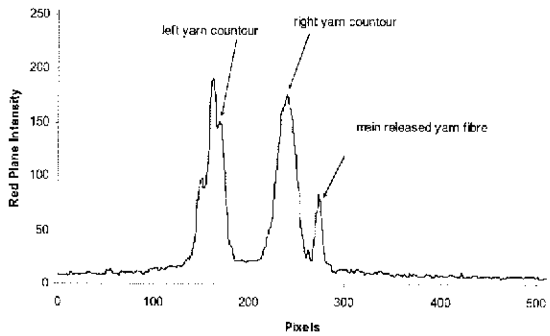

Figure 5. Line profile analysis example

The yarn diameter characterization can be determined considering the number of pixels between the left and right yarn contour pixels, the optical amplification (0.37) and the pixels pitch.

An experimental setup was developed based on the S8378-256Q CMOS line array and the C9001 Driver Circuit, both from Hamamatsu [10]. The main characteristics of the line array are: 256 pixels, pixel pitch of 25 μm, pixel height of 0.5 mm, maximum operating clock frequency of 500 kHz, spectral response range from 200 nm to 1000 nm, relatively sensitivity between 80 % and 100 % for the used wavelength, sensitivity of 4.4 V/lx.s, on-chip charge amplifier, built-in timing generator, typical dark output voltage of 1.6 mV for low gain (used), typical saturation output voltage of 2.5 V for low gain, typical saturation exposure of 570 mlx.s for low gain and quartz window material. The data acquisition, control and processing is performed using the data acquisition board and software developed in LabVIEW® [11].

The yarn mass variation system considers a 1 mm parallel plate capacitive sensor based on the integrated circuit MS3110 from Irvine Sensors [13, 14], allowing direct yarn mass measurements in samples of 1 mm. The sensor adopts a differential configuration to assure a higher robustness to variations in temperature, air humidity and pressure. It integrates transducer amplification and signal conditioning as shown in Fig. 6.

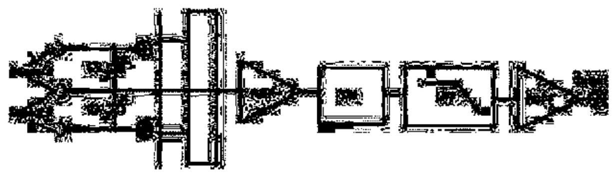

Figure 6. Capacitive sensor configuration [C1,C2 – Adjustable capacitors to calibrate the sensors, AMP – Capacity to voltage converter and amplifier, S/H – Sample and hold, LPF – Two pole low pass filter, and BUFF – Output buffer]

As Fig. 6 shows, the sensor capacitance variation is converted into a voltage signal and amplified. A second order low-pass filter attenuates the high frequency interferences that come from an internal oscillator and other external noise sources. The filtered signal is then once more amplified. The signal output is acquired by the data acquisition board and monitored in a PC, using a LabVIEW® software application [11].

III. Comparison Between Uster Tester 3 and YSQ

A comparison between statistical and signal processing results obtained with the YSQ prototype (Fig. 1) and the commercial solution Uster Tester 3, for a yarn sample (59 g/km linear mass 100 % cotton yarn) was performed.

A. *Statistical Results*

Due to the eight times superior resolution of the YSQ capacitive mass measurements (yarn samples of 1 mm length), it is verified that as expected, the measurements of U, CV and irregularities, present a significantly higher variations in comparison to the Uster Tester 3 (see columns (a) and (b) of Table I and their respective variations in Table II). Furthermore, since the YSQ does not consider the yarn contours as hairiness, as they are a characteristic of the yarn and are not hairiness, (contrary to the Uster Tester 3), the YSQ presents a much lower hairiness coefficient than the Uster Tester 3. The difference obtained is justified as the signal due to yarn contours is highly significant in the hairiness measurement in the Uster Tester 3 measurements. Finally, as this signal (yarn contours) could be considered approximately constant for a specific yarn, the variations detected over it (hairs) remain similar, justifying the relative similarity obtained in the standard deviation of the hairiness coefficient (sH), on both instruments.

TABLE I. Statistical Parameters Results

Parameter	Uster Tester 3 (a) (capacitive and optical sensor)	YSQ (b) (capacitive and optical sensor)	YSQ (c) (photodiode array sensor)
U (%)	11.40	15.68	16.43
CV (%)	14.50	20.20	22.91
Thin Places (-50 %)	2/km	1345/km	62352/km
Thick Places (50 %)	54/km	7365/km	8235/km
Neps (>= 200 %)	17/km	255/km	3529/km
H	8.20	1.45	1.52
sH	2.30	2.47	2.61

TABLE II. Statistical Parameters Results Absolute Variation

Parameter	Absolute variation (b - a)	Absolute variation (b - c)
U (%)	+ 4.28	- 0.75
CV (%)	+ 5.70	- 2.71
Thin Places (-50 %) / km	+ 1343	- 61007
Thick Places (+50 %) / km	+ 7311	- 870
Neps (>= +200 %) / km	+ 238	- 3274
H	- 6.75	- 0.07
sH	+ 0.17	- 0.14

In addition, to show the YSQ's capability of yarn parameterization using only one photodiode array, Table II also presents a comparison between the YSQ data obtained using capacitive and optical sensors (column (b) of Table I) and obtained using a photodiode array (column (c) of Table I). Observing these two YSQ data columns in Table I and their respective variations in Table II, it is demonstrated that almost all tested parameters show nearly identical results, especially absolutely, as expected for the yarn hairiness parameters (H and sH), as a result of their similar measurement technology (optics based). Furthermore, even the results of U and CV, considering different technologies of measurement (capacitive/optical based) and different segments of the same yarn are highly similar, resulting from the relationship between yarn mass and diameter. However, the results of irregularities present a significant variation. This situation is due to the superior resolution that characterizes the photodiode array and from the influence of yarn hairiness and contours in the capacitive sensor, increasing considerably in some cases the yarn mass value, which is not verified in the diameter measurements. Although, as observed, the dispersion indicators remain approximately similar, enabling a reliable yarn characterization using the photodiode array.

B. Signal Processing Results

Comparing Fig. 7, 8, 9 and 10 it is observed that the signals are very similar (mathematically) considering the same wavelength ranges (2 cm to 200 m). So, among others, all protruding wavelengths identified by the spectrograms of Uster Tester 3 (A to G in the mass spectrogram of Fig. 7 and A to F in the hairiness spectrogram of Fig. 9), were also identified by the spectrograms of the YSQ (A' to G' in the mass spectrogram of Fig. 8 and A' to F' in the hairiness spectrogram of Fig. 10). However, due to the higher acquisition frequency used in the YSQ (1 mm samples), it is possible to detect wavelengths in the]2 mm, 2 cm[range, which are impossible with the longer samples measured by the Uster Tester 3. As cotton fiber lengths are in this range, this feature allows a more detailed quality analysis [14].

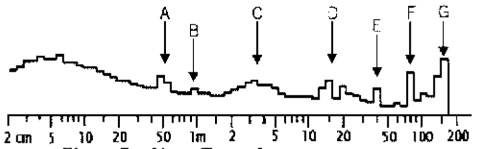

Figure 7. Uster Tester 3 mass spectrogram

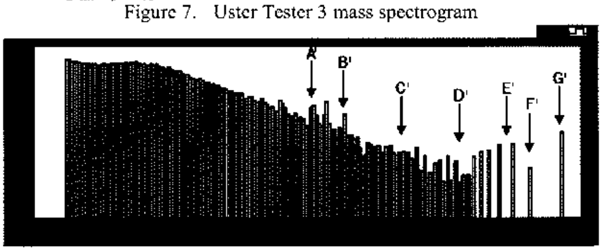

Figure 8. YSQ mass spectrogram

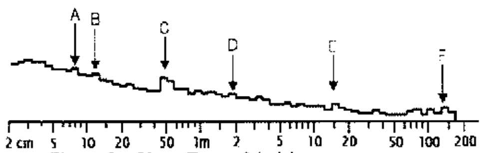

Figure 9. Uster Tester 3 hairiness spectrogram

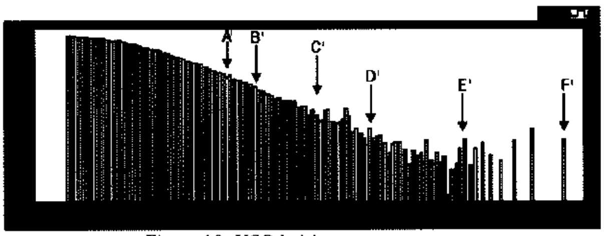

Figure 10. YSQ hairiness spectrogram

IV. Conclusions and Future Work

In comparison with the available commercial systems, the YSQ presents several new characteristics, namely: the simultaneously use of the coherent optical signal processing for yarn hairiness and diameter characterization; auto-calibration procedures of yarn hairiness reference [15] and diameter determination [9]; integration and measurement of yarn mass variation based on 1 mm capacitive sensor enabling the direct detection of nep irregularities; determination of new parameters in yarn analysis allowing a high precise yarn characterization; use of three signal processing techniques, enabling an accurate periodical errors characterization; automatic determination of yarn production characteristics; modular integration of yarn mass measurement, hairiness measurement, diameter variation measurement and precise diameter determination; reduced dimension, enabling a high portability; application in laboratorial analysis or in Industry for yarn quality control. In summary, the YSQ is characterized by low cost, superior yarn parameterization and high resolution and precision. This permits a lower waste, resulting from the reduction of the yarn sample length analysis and allows a quality control for the desired producer level of yarn sensitivity.

Further work will evolve the YSQ to a more compact and lighter commercial prototype including, as an example, a user touch screen interface and a report printer and the possibility of measuring precisely yarn diameter and hairiness using a single line array based system with custom and fast developed hardware and software to reduce the computational effort and increase efficiency.

Acknowledgment

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

References

[1] www.uster.com (access in June 2008)

[2] www.zweigle.com (access in June 2008)

[3] A. Barella, "The Hairiness of Yarns", Textile Progress, 1992, 24, p3.

[4] J. Neves, "A Irregularidade dos Fios Têxteis, Sua Origem, Medição e Análise", Oporto, 1968.

[5] R. Furter, "Evenness Testing in Yarn Production: part I", The Textile Institute and Zellweger Uster AG, Manchester, 1982.

[6] B. Goswami, J. Martindale and F. Scardino, "Textile Yarns: Technology, Structure and Applications", 2nd Edition, John Wiley & Sons, New York, 1977.

[7] www.thorlabs.com (access in June 2008)

[8] V. Carvalho, P. Cardoso, M. Belsley, R. Vasconcelos and F. Soares, "Yarn Hairiness Parameterization Using a Coherent Signal Processing Technique", Sensors and Actuators A: Physical, Volume 145, Issue 1, p217-224.

[9] V. Carvalho, P. Cardoso, M. Belsley, R. Vasconcelos and F. Soares, "Yarn Diameter Measurement Using Coherent Optical Signal Processing" (accepted for publication in IEEE Sensors Journal).

[10] www.hamamatsu.co.jp (access in June 2008)

[11] www.ni.com (access in June 2008)

[12] V. Carvalho, M. Belsley, R. Vasconcelos and F. Soares, "Yarn Hairiness and Diameter Characterization Using a CMOS Line Array", Measurement Journal, 2008, doi:10.1016/j.measurement.2008.02.010.

[13] www.irvine-sensors.com (access in June 2008)

[14] V. Carvalho, J. Pinto, J. Monteiro, R. Vasconcelos and F. Soares, "Yarn Parameterization Based on Mass Analysis", Sensors and Actuators A: Physical, Volume 115, Issues 2-3, 21, p540-548.

[15] V. Carvalho, P. Cardoso, M. Besley, R. Vasconcelos and F. Soares, "A New Statistical Reference Method for Yarn Hairiness Quantification", ISIE 2007, 4-7 June, Vigo, Spain, p.1864-186.