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DEVELOPMENT OF AN AUTOMATIC YARN CHARACTERIZATION SYSTEM

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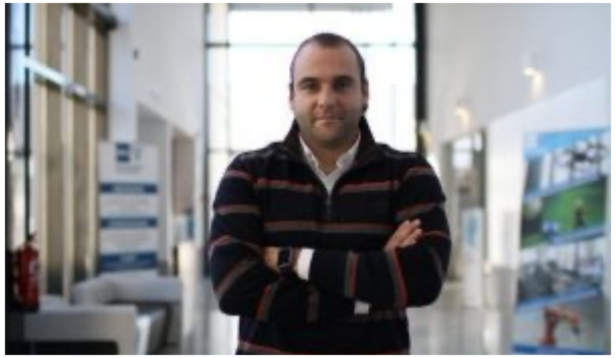

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INTRODUCTION
BACKGROUND AND MOTIVATION

THE CORRECT AND ACCURATE EVALUATION OF YARNS IS A SUBJECT OF **MAJOR IMPORTANCE** TO THE TEXTILE INDUSTRY.

FINAL FABRIC QUALITY DEPENDS **DIRECTLY** ON THE YARN QUALITY.

INTRODUCTION
BACKGROUND AND MOTIVATION

TESTERS FROM USTER AND THE MULTITESTER FROM ZWEIGLE ARE NOTABLE FOR THEIR **RELEVANT CONTRIBUTIONS.**

Fig.1 - Uster Tester 6

Fig.2 - Zweigle Multitester

INTRODUCTION
BACKGROUND AND MOTIVATION

ALTHOUGH, THESE EQUIPMENT ARE OF A SIGNIFICANT COST, REQUIRE A CONSIDERABLE AREA FOR THEIR INSTALLATION AND PRESENT **LIMITED RESOLUTION** AND **PRECISION** IN THE EVALUATION OF CERTAIN YARN PARAMETERS.

TYPICALLY YARN PRODUCERS DO NOT HAVE THEIR OWN YARN TESTERS - SUBCONTRACT EVALUATIONS FROM DEDICATED TESTING LABORATORIES.

TIME CONSUMING PROCESS, **ELIMINATES** THE POSSIBILITY OF **ACTING IN USEFUL TIME** DURING YARN **PRODUCTION**, REDUCING EFFICIENCY.

INTRODUCTION
MAIN OBJECTIVE

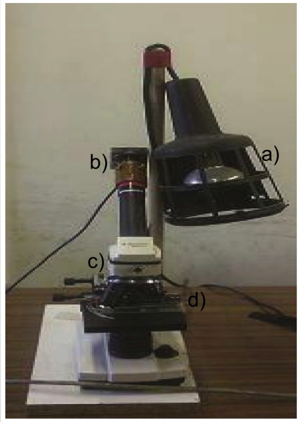
DEVELOP AN AUTOMATIC SYSTEM TO CHARACTERIZE YARN QUALITY WITH A SUPERIOR LEVEL OF PARAMETERIZATION IN COMPARISON TO THE COMMERCIAL SOLUTIONS.

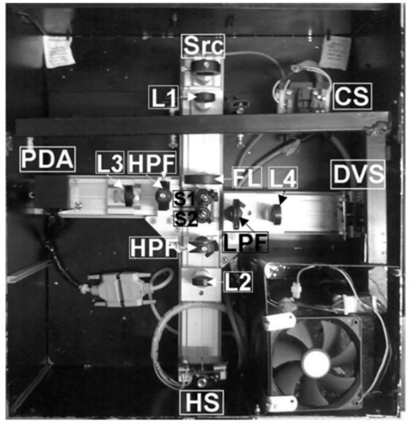
SIGNIFICANTLY INCREASE THE INFORMATION ACCESSIBLE TO YARN PRODUCERS ALLOWING AN EFFICIENT YARN PRODUCTION.

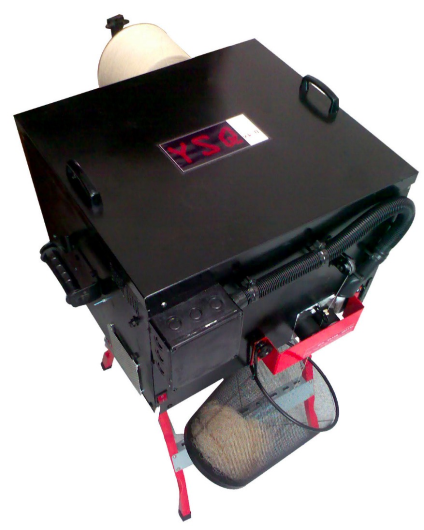
INTRODUCTION
PROJECT TIMELINE

(2010-Present)
YSQ-IP prototypes: (v1) image processing - **with yarn movement;**
v2 prototype: to include hairiness characterization + fabrics prediction (AI).

- **(2002-2008)**
- **YSQ PROTOTYPE:** YARN MASS (CAPACITIVE), YARN HAIRINESS AND DIAMETER (OPTICAL) AND YARN PRODUCTION CHARACTERISTICS (IMAGE PROCESSING).

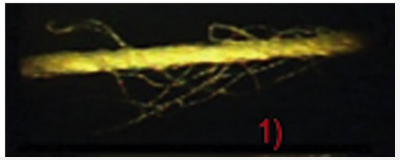


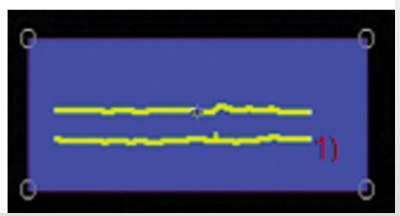


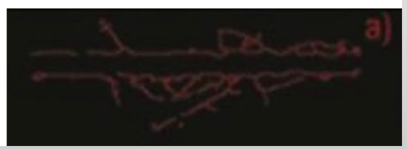


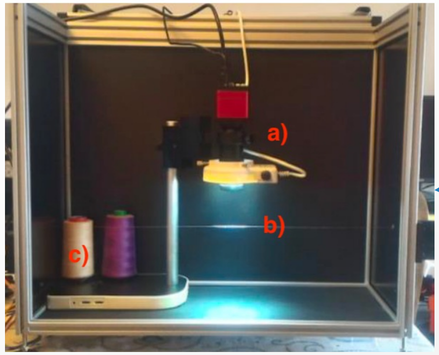
YSQ

(2008-2010)
yarn diameter, irregularities and hairiness (image processing)
- no yarn movement.

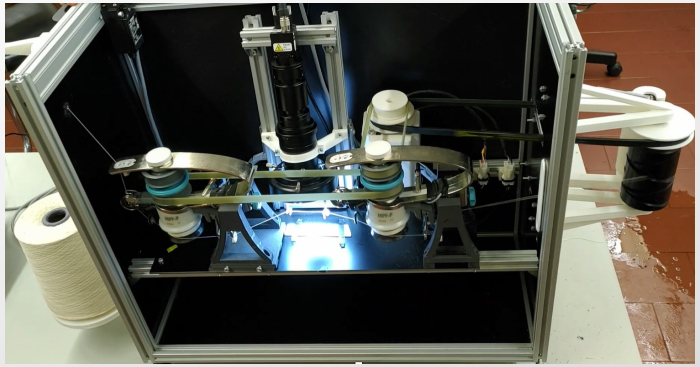








YSQ-IP (v1)



YSQ-IP (v2)

THEORETICAL CONCEPTS
YARN CONFIGURATION

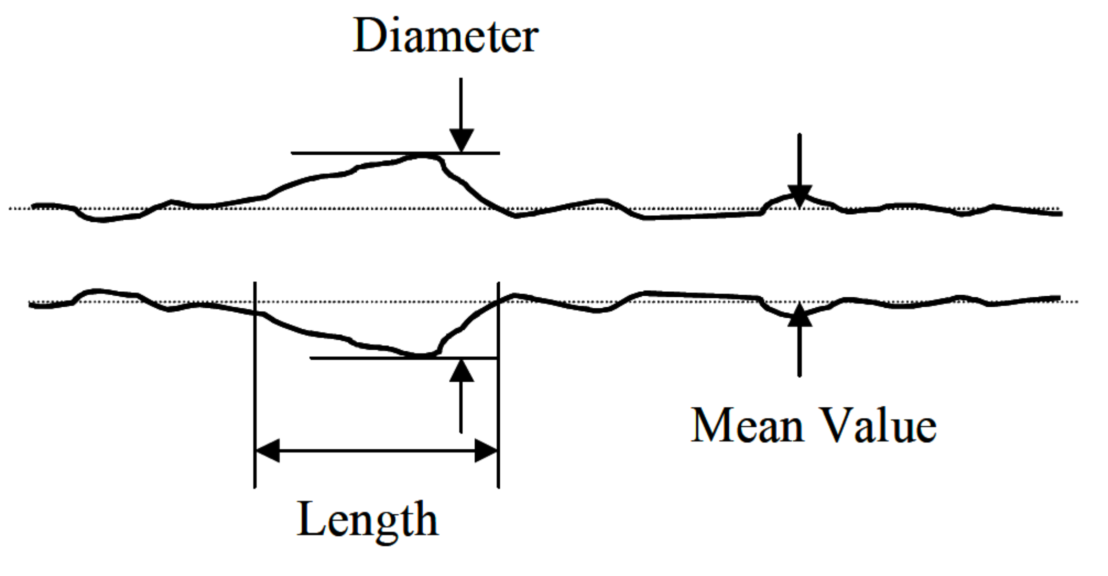


Fig.3 –Example of Yarn Configuration

$$\text{Yarn}_{\text{diameter}} = 4{,}44x10^{-2}\sqrt{\frac{tex}{p}}\ (mm)$$

Where:

tex - yarn linear mass (g/km);

p - yarn density (g/cm³).

THEORETICAL CONCEPTS
YARN PARAMETERS

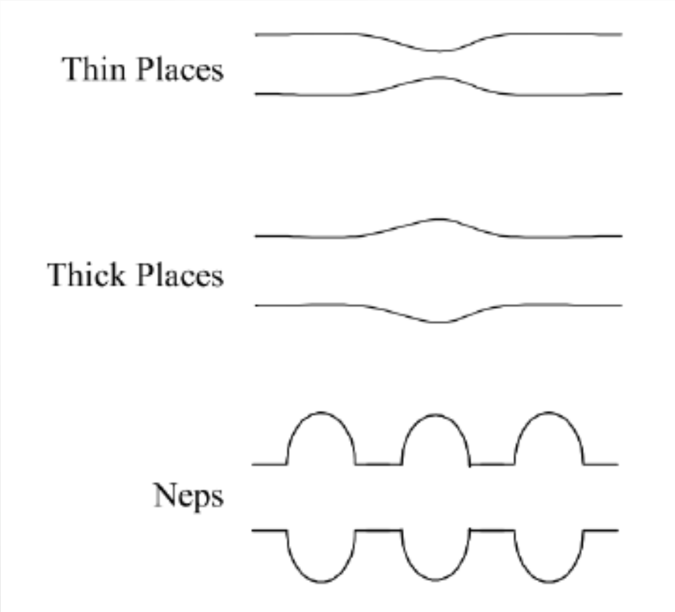


Fig.4 -Types of irregularities

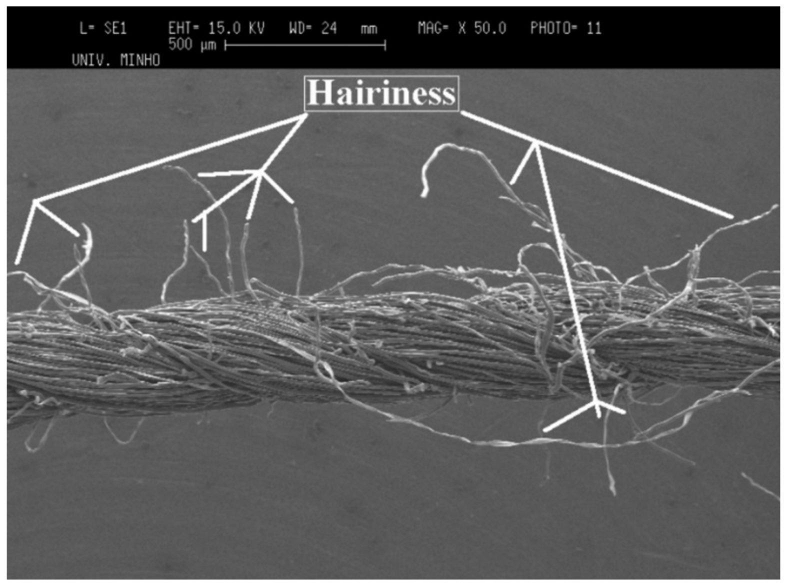


Fig.5 - Yarn hairiness

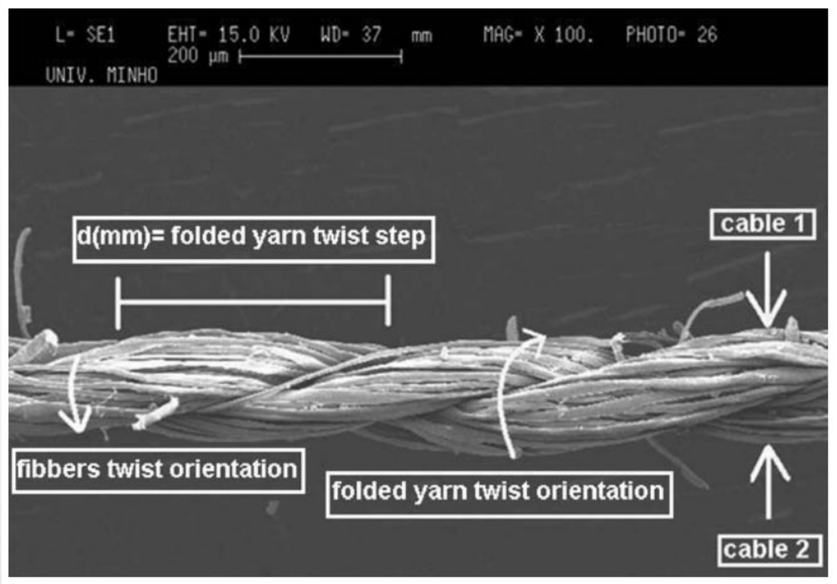


Fig.6 - Yarn production characteristics identification

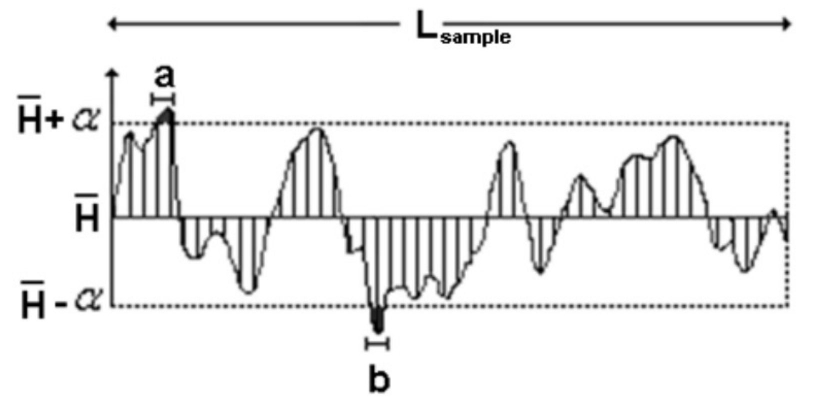
THEORETICAL CONCEPTS
COEFFICIENTS AND STATISTICAL PARAMETERS

$$H = \frac{l_H}{l_{yarn}}$$

Hairiness coefficient (H)

$$UH(\%) = \frac{100}{\overline{H} n_s} \sum_{i=1}^{n_s} \left| H_i - \overline{H} \right|$$

Absolute mean deviation of H



Deviation rate of H_α

$$sH = \sqrt{\frac{1}{n_s} \sum_{i=1}^{n_s} \left(H_i - \overline{H} \right)^2}$$

Standard deviation of H

$$CVH(\%) = \frac{100}{\overline{H}} \sqrt{\frac{1}{n_s} \sum_{i=1}^{n_s} \left(H_i - \overline{H} \right)^2}$$

Coefficient of variation of H

$$IDRH_\alpha(\%) = \frac{\sum_{i=0}^{n_s - 1} y(i)}{\overline{H} n_s} 100$$

$$y(i) = \begin{cases} \left| H_i - (\overline{H} + \alpha) \right| & if \quad H_i \geq \overline{H} + \alpha \\ 0 & if \quad \overline{H} - \alpha < H_i < \overline{H} + \alpha \\ \left| H_i - (\overline{H} - \alpha) \right| & if \quad H_i \leq \overline{H} - \alpha \end{cases}$$

Integral deviation rate of H_α

The statistical parameters can be applied to mass and diameter.

THEORETICAL CONCEPTS
SIGNAL PROCESSING TECHNIQUES

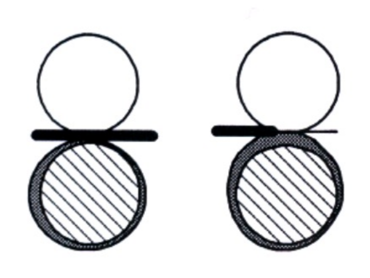


Fig.7 - Accumulated dirt error (sinusoidal imperfection)

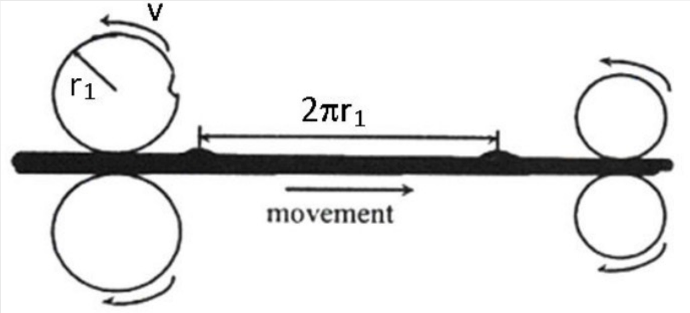


Fig.8 - Imperfection on the roller surface (periodical impulse error)

Certain errors detection require different signal processing approaches.

FFT (sinusoidal errors)

FWHT (rectangular errors)

FDFI (impulse errors)

YARN MASS PARAMETERIZATION USING 1MM CAPACITIVE SENSORS (PHASE 1)

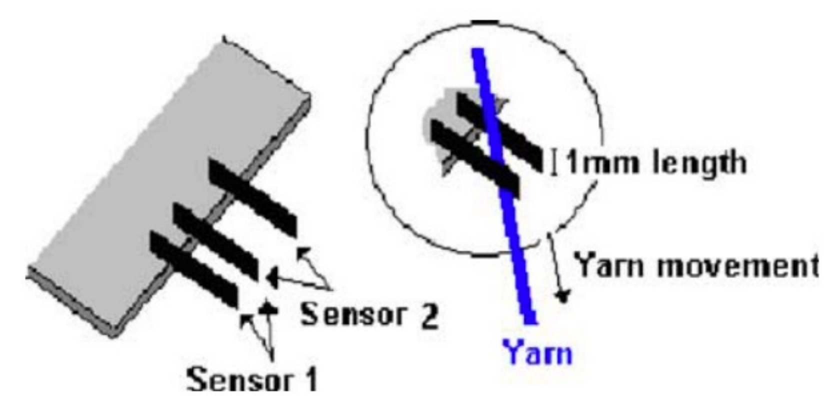


Fig.9 - Multiple parallel plates capacitive sensor

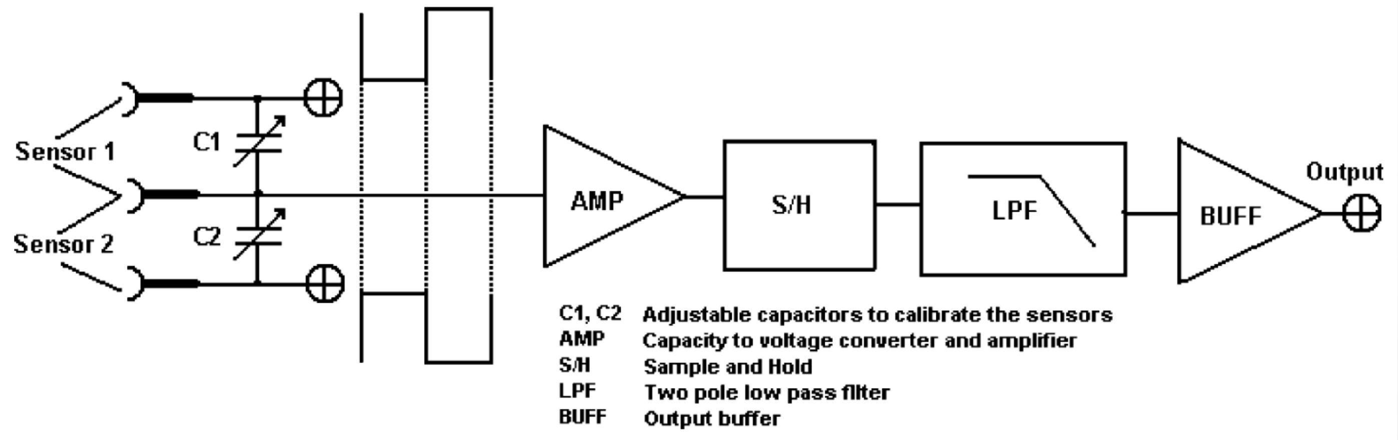


Fig.10 - Dual sensor parallel plates and MS3110 IC block diagram

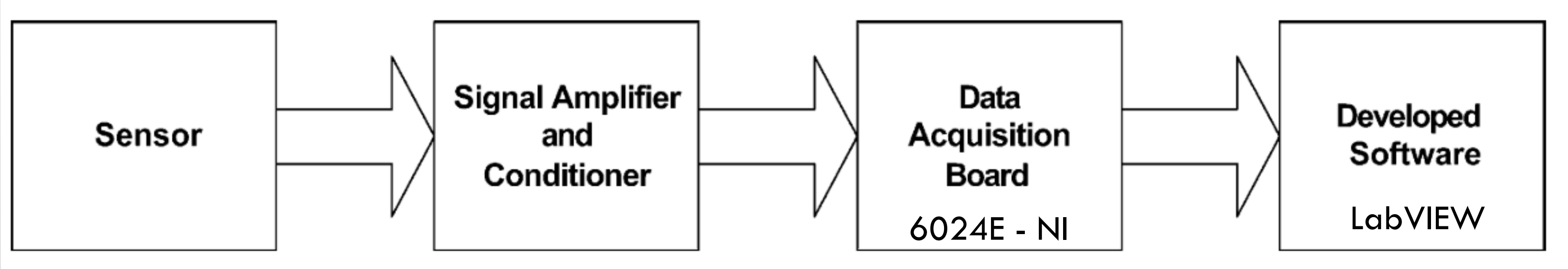


Fig.11 - Yarn mass measurement system flowchart

Capacitance variation of 2,08E-17F is expected for a 57tex yarn.

YARN MASS PARAMETERIZATION USING 1MM CAPACITIVE SENSORS (PHASE 1)

- **TEST:**
  - YARN: 19,7TEX (G/KM) COTTON YARN;
  - SPEED OF YARN: 50M/MIN;
  - F=833HZ;
  - SENSOR WIDTH = 1MM;
  - SAMPLE LENGTH = 1000M.

- **SENSITIVITY THRESHOLDS:**
  - THIN AND THICK PLACES;
    - 20,40,60,80 (%).
  - NEPS;
    - 100,150,200,250(%).

Sensitivity is defined as the yarn mass value used to detect a particular irregularity!

YARN MASS PARAMETERIZATION USING 1MM CAPACITIVE SENSORS (PHASE 1)

Statistical Parameters & Irregularities Results

Table 1 - Thin and thick places for 1mm samples

Faults length (mm)	Sensitivity (%)							
	20		40		60		80	
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
1	38823	48013	3488	5229	97	313	8	18
2	7414	7875	132	233	0	26	0	0
3	2137	1917	13	49	0	5	0	0
>3	2335	1555	6	96	0	4	0	0
Total	50769	59360	3639	5607	97	348	8	18

Table 2 - U(%), CV(%), DR(%), IDR(%) and neps for 1mm samples

Sensitivity (%)	DR (%)	Length (m)	IDR (%)	Sensitivity (%)	Neps	U (%)	CV (%)
20	25.23	252.34	5.71	100	8	11.23	14.04
40	1.78	17.75	0.64	150	0		
60	0.05	0.50	0.02	200	0		
80	0.00	0.00	0.00	250	0		

YARN MASS PARAMETERIZATION USING 1MM CAPACITIVE SENSORS (PHASE 1)

Statistical Parameters & Irregularities Results

Table 3 - U(%), CV(%), DR(%), IDR(%) and neps for 8mm samples (mathematical model)

Sensitivity (%)	DR (%)	Length (m)	IDR (%)	Sensitivity (%)	Neps	U (%)	CV (%)
20	4.87	48.70	1.09	100	0	8.26	10.33
40	0.11	1.10	0.04	150	0		
60	0.004	0.04	0.00	200	0		
80	0.00	0.00	0.00	250	0		
			Uster classification (%)		$P < 5$	$P < 5$	$P < 5$

Table 4 - Thin and thick places for 8 mm samples (mathematical model)

Faults length (mm)	Sensitivity (%)							
	20		40		60		80	
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
8	4125	1943	6	139	0	5	0	0
Total	4125	1943	6	139	0	5	0	0
Uster classification (%)	$P > 95$		$P = 25$		$P < 5$		$P < 5$	

YARN MASS PARAMETERIZATION USING 1MM CAPACITIVE SENSORS (PHASE 1)

Signal Processing Results

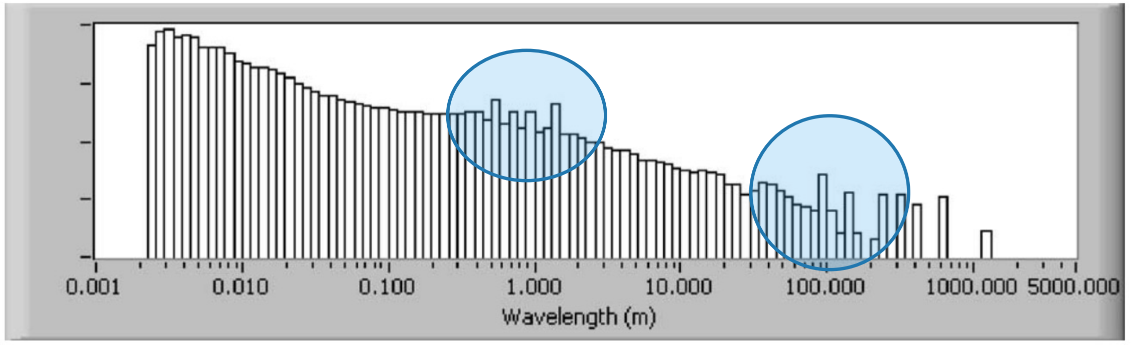


Fig.12 - Spectrogram for 1mm samples

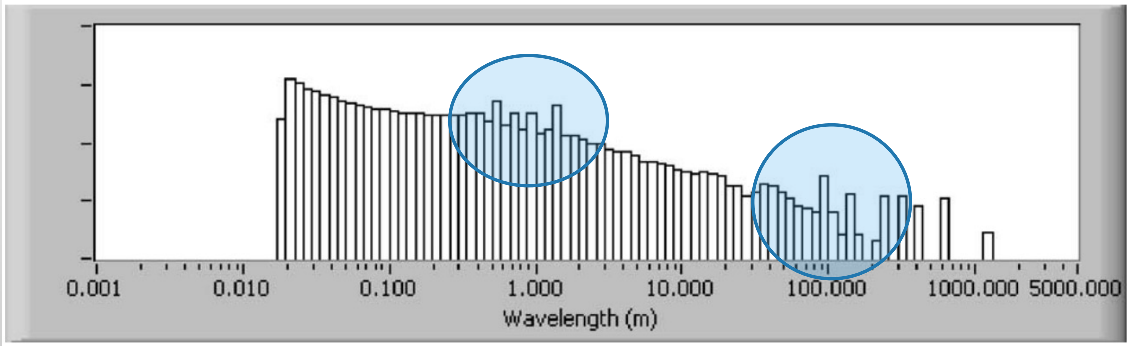


Fig. 13 - Spectrogram for 8mm samples (mathematical model)

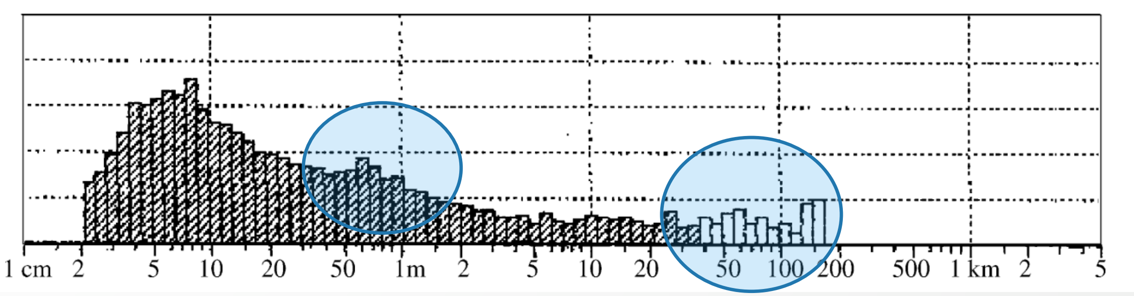


Fig.14 - Spectrogram for 8mm samples with Uster Tester 3

Uster Tester 3 vs Developed System:

-the signals are very similar (mathematically).

Slight differences:

-for different tests, with the same yarn, the number of irregularities varies in number and type;

-the main tendency of the spectrum should prevail, as occurred.

YARN MASS PARAMETERIZATION USING 1MM CAPACITIVE SENSORS (PHASE 1)

Project Achievements – phase 1

- **the evaluation of yarn mass with the developed sensor is feasible at 1mm range;**
- we were able to extract yarn mass values of 1mm, which can be compared, using mathematical treatment, with Uster standard tables (8mm yarn samples).

YARN HAIRINESS PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 2)

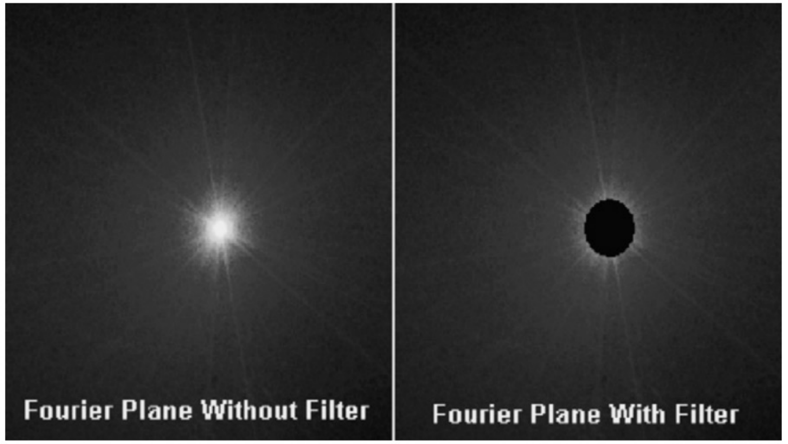


Fig.15 - Optical signal processing – Fourier Plane

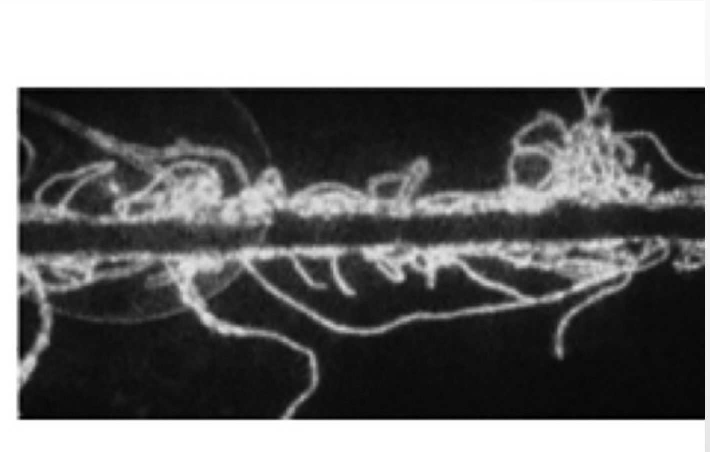


Fig.16 - High pass spatial filter (hairiness)

YARN HAIRINESS PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 2)

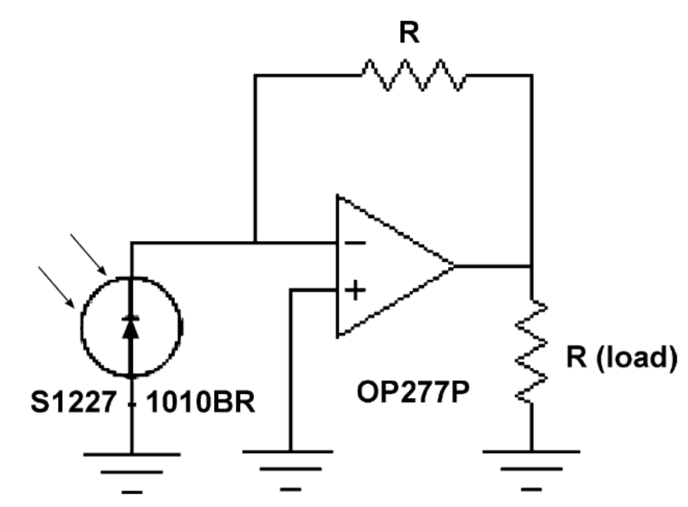


Fig.17 - Current to voltage converter

$$V_{R_{\text{load}}} = -RI_{\text{photodiode}}$$

F is a high-pass spatial Fourier filter.

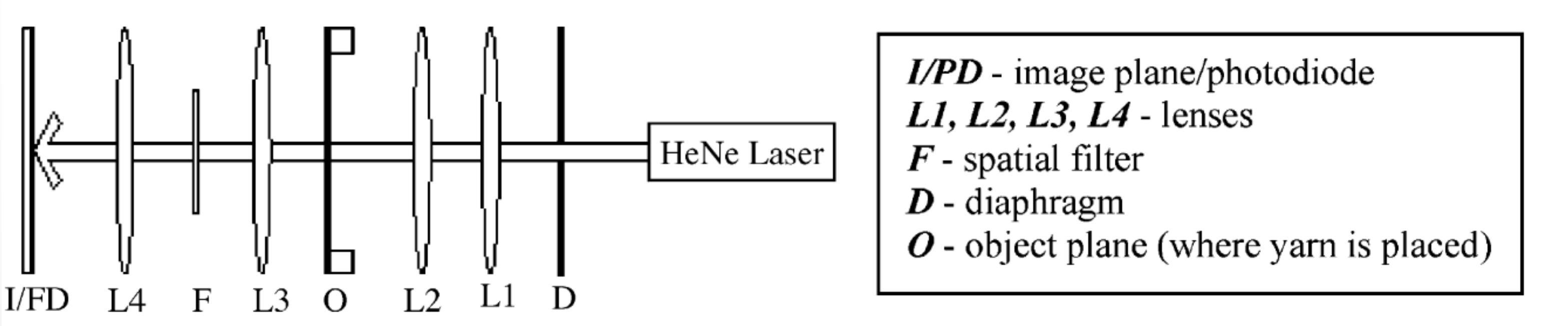


Fig.18 - Optical system design

$$\text{Var}_{\text{Hairiness}}(\%) = \frac{X_i - V_m}{V_m - V_{wh}} \times 100$$

YARN HAIRINESS PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 2)

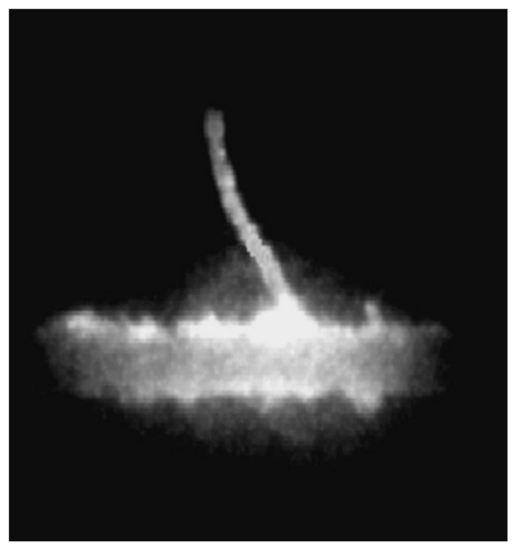


Fig.19 - Fiber isolation - 0.64mm diameter yarn

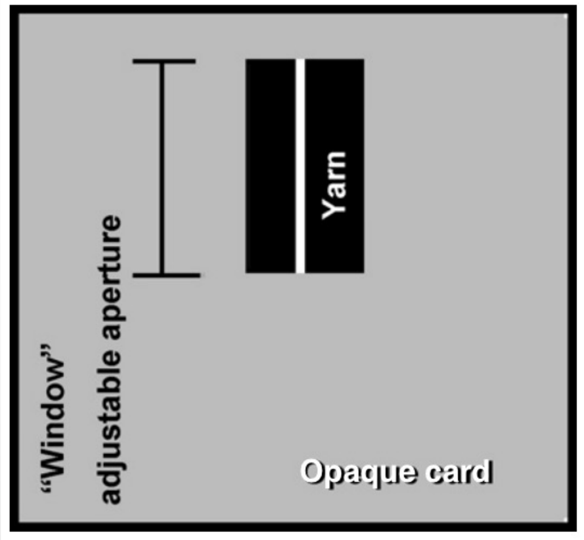


Fig.20 - Opaque card with adjustable window

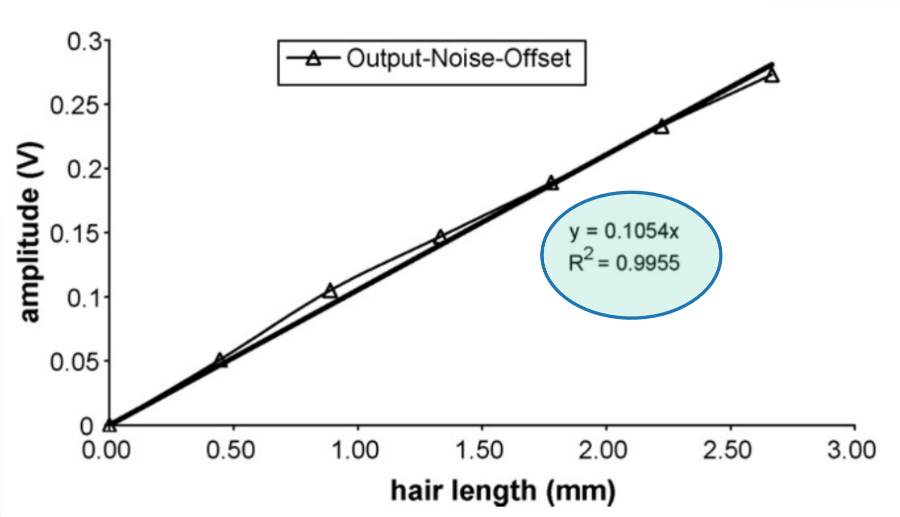


Fig.21 - Hairiness length calibration curve

Hairiness Measurement Length Calibration

1mm hairiness – 105,4mV

YARN HAIRINESS PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 2)

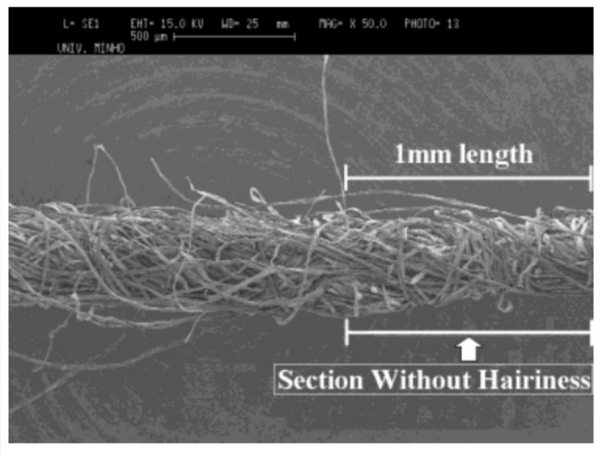


Fig.22 - Image of a yarn with a region of 1mm without hairiness

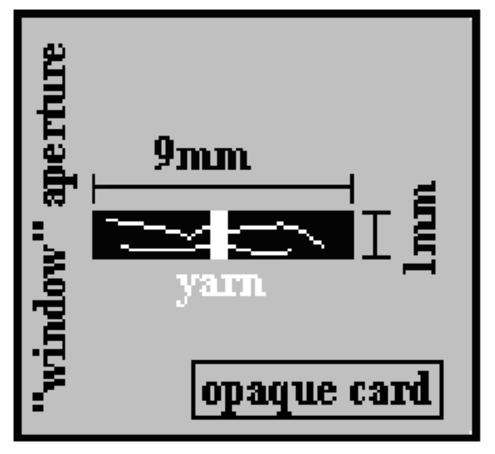


Fig.23 - "Mask" used

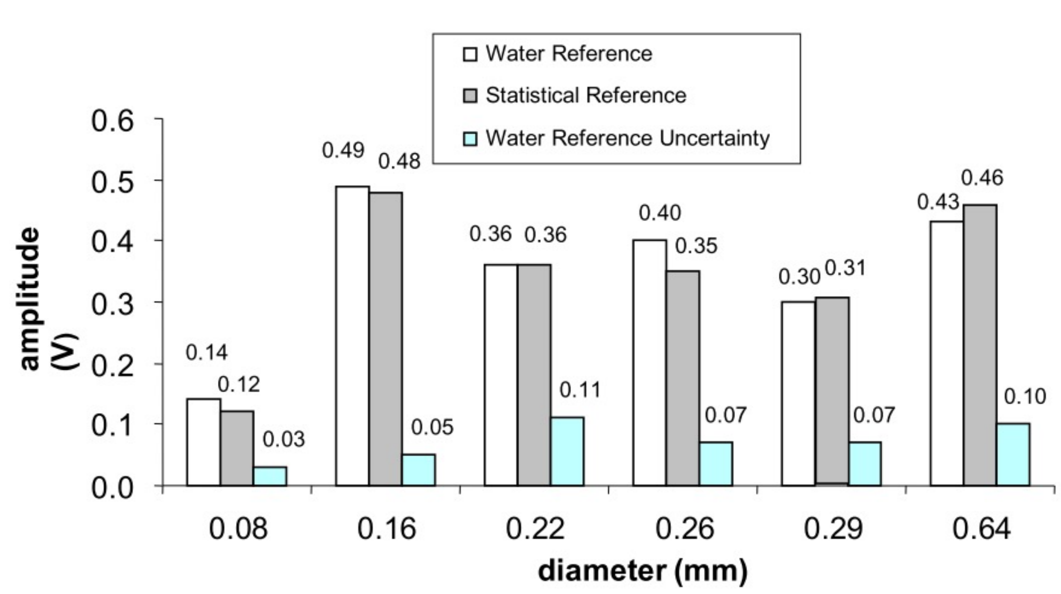


Fig.24 - Minimum statistical reference vs water reference results

Minimum Statistical Reference Method

YARN HAIRINESS PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 2)

Statistical Parameters Results

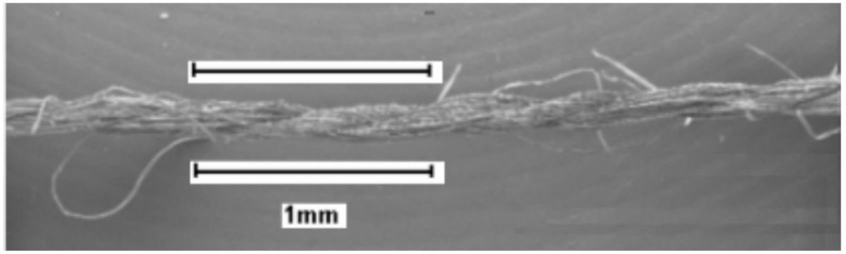


Fig.25 - Electron microscope image of the tested 4.2tex yarn (34X)

Table 5 - Main statistical parameters of hairiness

Parameter	Result
H	0.21
CVH (%)	10.48
sH	2.19
UH (%)	4.43

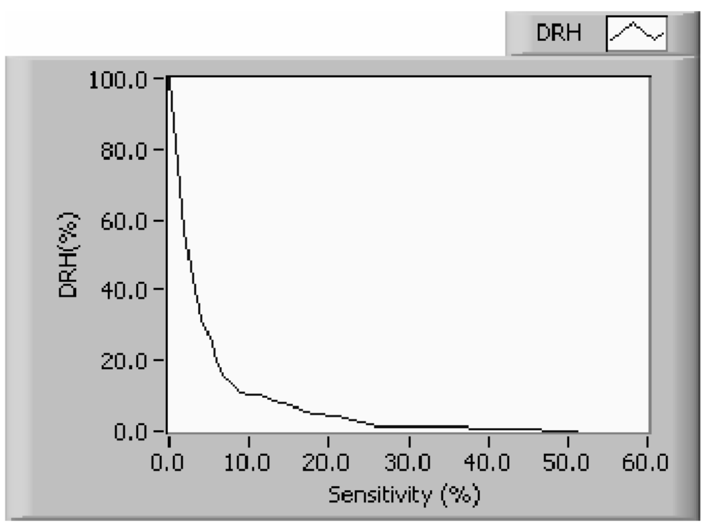


Fig.26 - DRH(%) results

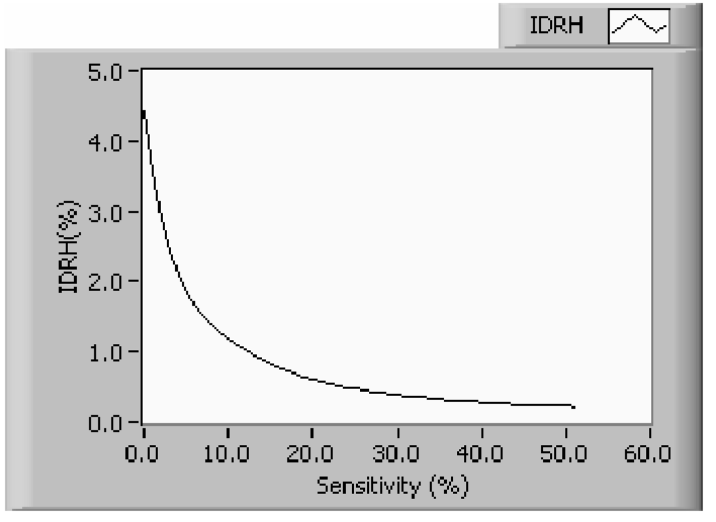


Fig.27 - IDRH(%) results

YARN HAIRINESS PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 2)

Signal Processing Results

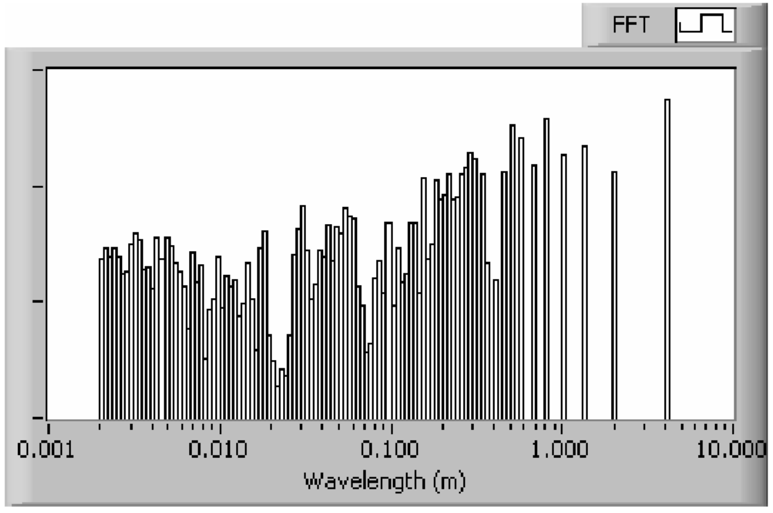


Fig.28 - FFT of hairiness variation spectrogram

Several peaks but none dominating: non-sinusoidal signal characteristic.

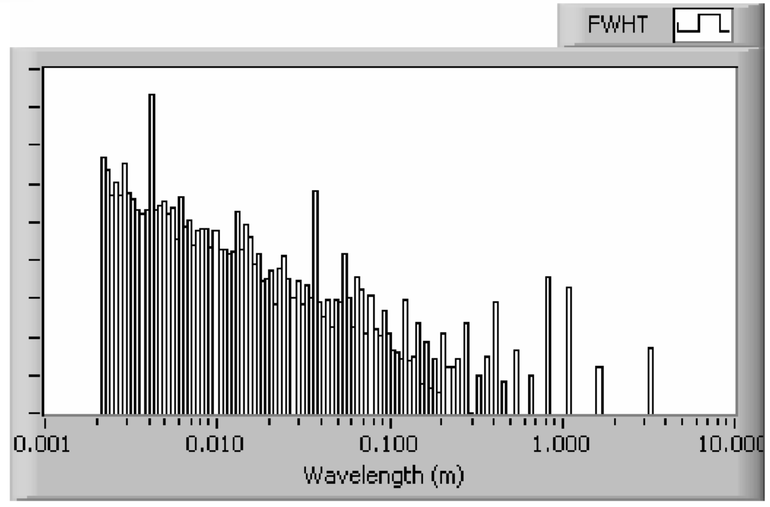


Fig.29 - FWHT of hairiness variation spectrogram

Several peaks protrude: rectangular similarity signal – more adequate for H.

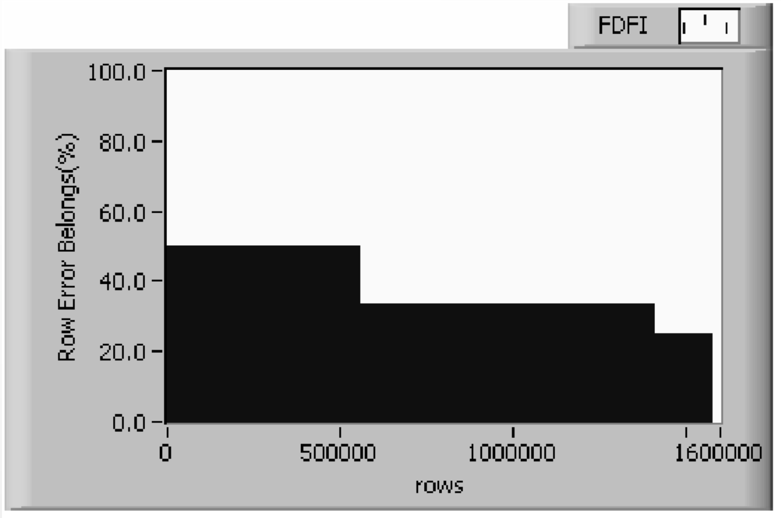


Fig.30 - FDFI row error belongings

No periodic impulse errors for 25% threshold – no 100% row error belongings.

YARN HAIRINESS PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 2)

Project Achievements – phase 2

- The **methodology** used to the hairiness determination (coherent optical signal processing plus electronics) yields reliable results (low noise, stability and high linearity, factors which increase both resolution and accuracy);
- The **statistical reference method** enables the determination of the signal reference with the advantages of being non evasive and the possibility of being determined simultaneously with the data acquisition;
- **This allows a feasible determination of the yarn hairiness statistical parameters and spectrograms.**

YARN DIAMETER PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 3)

- SIMILAR ELECTRONIC AND OPTICAL HARDWARE AS FOR HAIRINESS DETECTION, BUT WITH **F** BEING A **LOW-PASS** SPATIAL FOURIER FILTER.

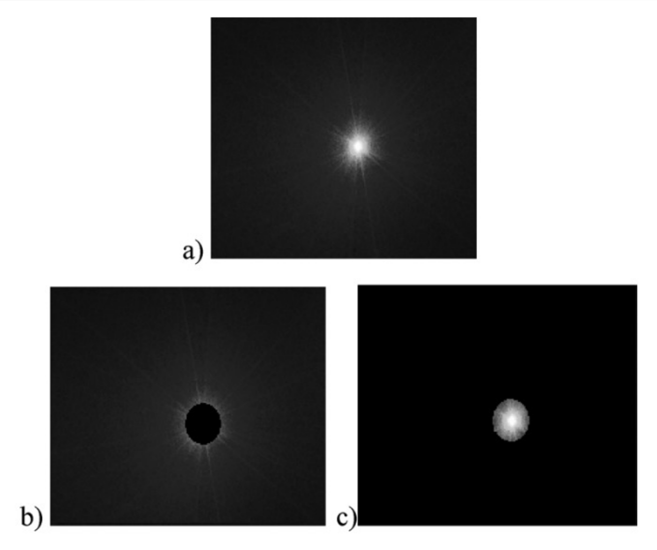


Fig.31 - Fourier plane (a); Result with (b) high-pass filter and (c) low-pass filter

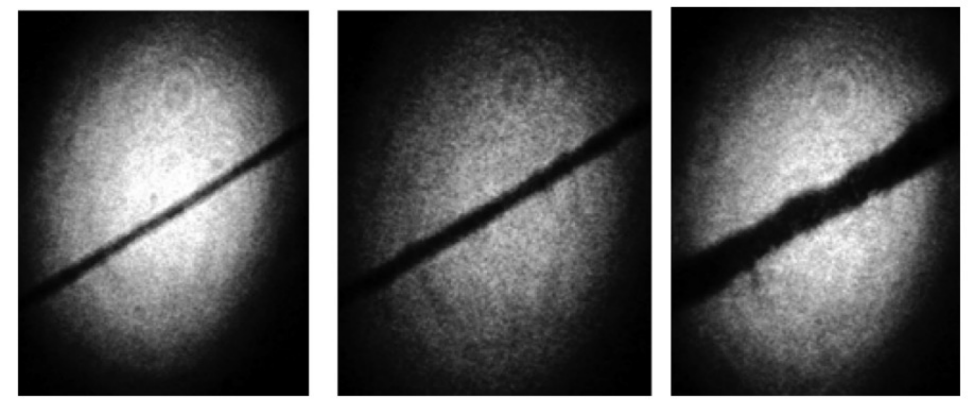


Fig.32 - Examples of the application of a low-pass filter in yarns

YARN DIAMETER PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 3)

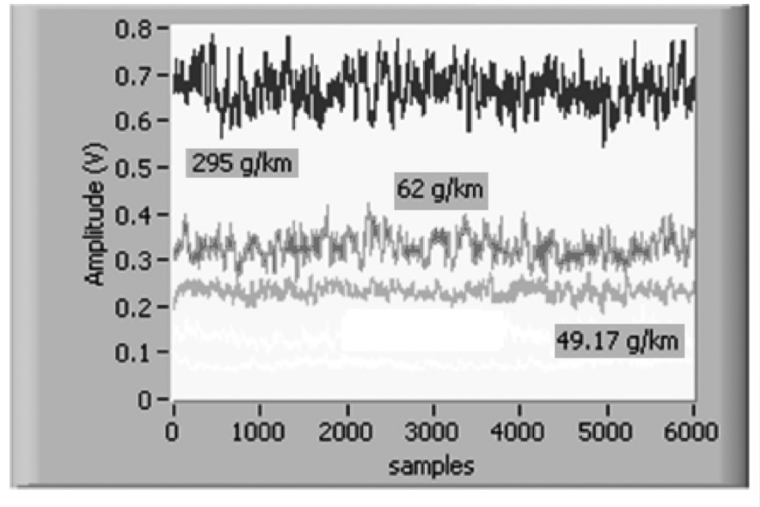


Fig.33 - Signal output for the tested yarns (blocked signals)

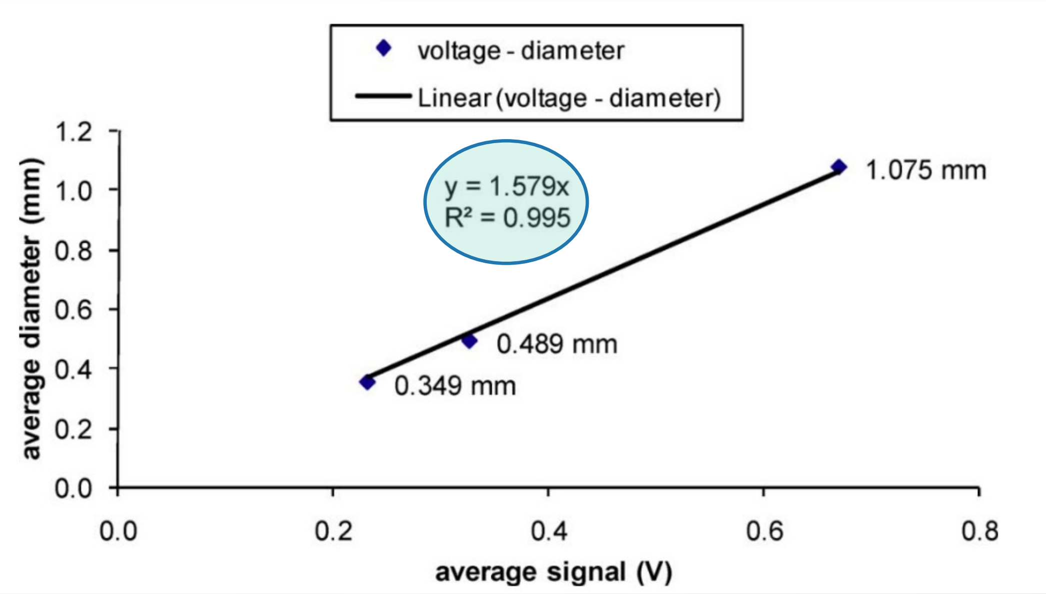


Fig.34 - Linear distribution of the yarn diameter

Table 6 - Relationship between yarn diameter and average output signals

Yarn linear mass (g/km)	Average signal (V)	Maximum diameter (mm)	Minimum diameter (mm)
49.17	0.2320	0.384	0.314
62.00	0.3265	0.518	0.460
295.00	0.6687	1.210	0.940

Diameter Measurement Calibration

1mm diameter – 633,3mV

YARN DIAMETER PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 3)

- **CORRELATION BETWEEN YARN MASS AND DIAMETER VARIATION RESULTS:**
  - TEST: 295TEX YARN;
  - CAPACITIVE AND OPTICAL SAMPLES OF 1MM;
  - 2 DIFFERENT SECTIONS OF THE SAME YARN.
    - EXPECT SIMILAR VARIATION RESULTS, BUT NOT IDENTICAL.

Table 7 - Descriptive analysis with SPSS

	Range (%)	Minimum (%)	Maximum (%)	Mean (%)	Mean SD error	Inter-quartile Range (%)	Covariance (%)
Optical	27.81	-14.00	13.81	0.17	0.15	6.58	25.37
Capacitive	26.82	-13.47	13.35	0.03	0.13	5.33	19.02

Capacitive and optical values are in close agreement. The correlation is at a **0.05% level - statistical significance** between both technologies.

YARN DIAMETER PARAMETERIZATION USING A COHERENT SIGNAL PROCESSING TECHNIQUE (PHASE 3)

Project Achievements – phase 3

- The **methodology** used to yarn diameter determination (coherent optical signal processing plus electronics) yields reliable results - direct relationship between the output system value and the yarn diameter;
- the **quantification of yarn irregularities** is easily achieved, considering the sample-by-sample diameter results, in order to the average diameter variation;
- A noncontrolled environment could be used as the system is able of **auto-calibration**!

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

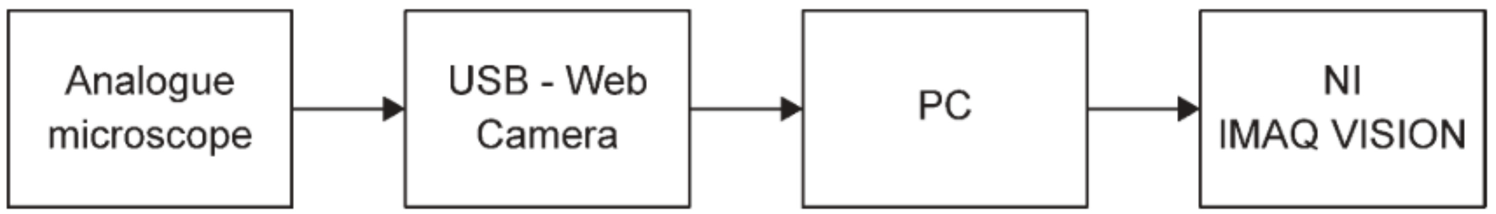


Fig.35 - Image acquisition system design

Analogue Microscope:

- Two oculars of 5x and 16x;
- Three objectives of 4x,10x, and 40x;
- A Barlow lens of 2x; and,
- Led illumination (monochromatic).

USB Web Camera:

- Photosensitive element: 1/4" CMOS sensor;
- Resolution: 640 x 480pixels;
- Video mode: VGA; and,
- Colour format: 24bits.

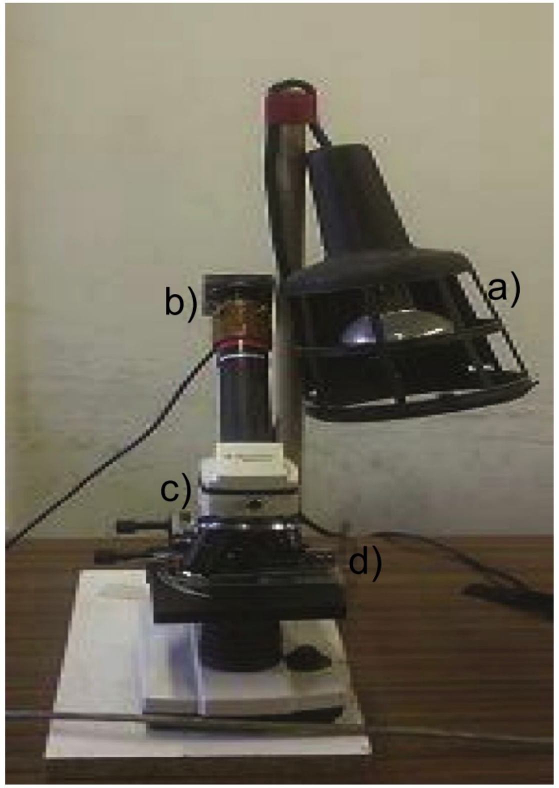
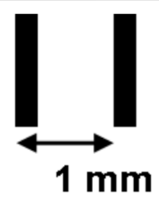


Fig.36 - Image acquisition hardware (a) monochromatic illumination (b)webcam (c)amplification lens (d) yarn samples



Calibration (40x): 1 pixel -> 1/73mm

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Fig.37 – Example of image acquisition of a 22tex yarn

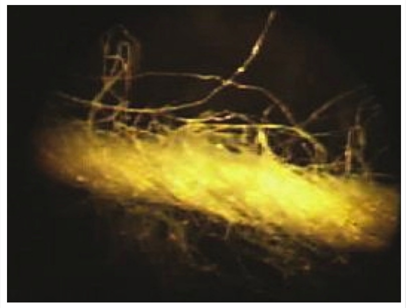


Fig.38 – Example of image acquisition of a 62tex yarn

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

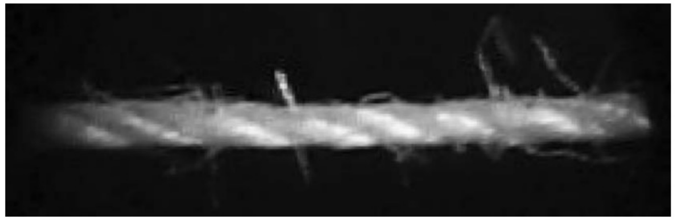
Developed applications to obtain the yarn production characteristics

- **Main Application** (A) – extraction of the relevant yarn image areas;
- **Yarn Production Characteristics Classification Application** (B) – analysis of the particles resultant from A;
- **Fibers Twist Orientation in Spun(Nonfolded) Yarns Application** (C)

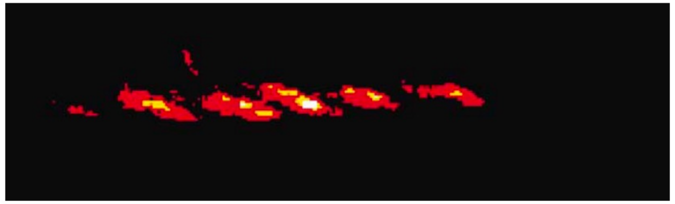
YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Main Application (A)

1



22tex yarn image acquired (1)

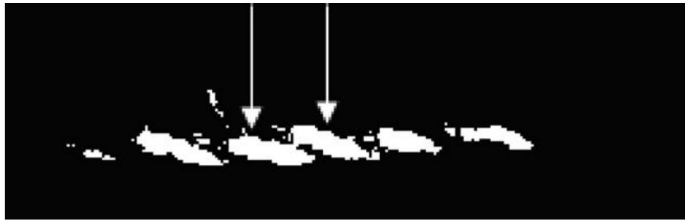


Contrast and Gamma adjust (2)

Removal of the Luminance Plane over Hue Saturation Plane (3)

2

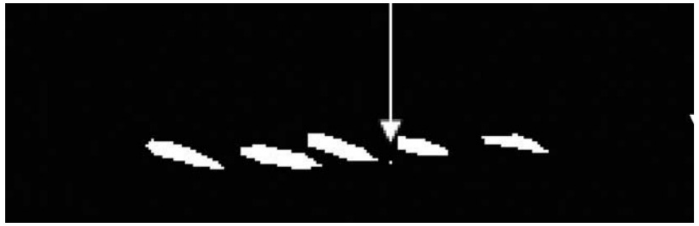
Segmentation:Binarization (4)



Hole Filling (5)

Erosion (6)

3



Convex Hull (7)

Small Object Removal (8) x2

Particle Analysis (9):
- First horizontal pixel;
- Orientation angle;
- Area.

Image Processing (IP) Techniques Sequence

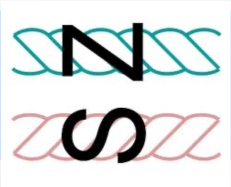
YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Folded yarn twist step

- average of the first horizontal pixel between particles.

Folded yarn twist orientation

- angle between 90^{a} and 180°: anticlockwise;
- angle between 0° and 90°: clockwise.



Number of cables

- 1 particle – spun (nonfolded) yarn;
- more than 1 particle - folded yarn.

Fibers twist orientation

- folded yarn - opposite to yarn twist orientation;
- spun yarn - App. C is considered.

Yarn Production Characteristics Classification Application **(B)**

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

1. REMOVAL OF THE INTENSITY PLANE OF THE HUE, SATURATION AND INTENSITY: COLOUR ENCODING SCHEME;
2. CONVOLUTION: HIGHLIGHT DETAILS;
3. AUTO THRESHOLD: MOMENTS;
4. SMALL OBJECTS REMOVAL;
5. LABELLING;
6. EXPONENTIAL;
7. CONVEX HULL;
8. PARTICLE FILTER;
9. PARTICLE ANALYSIS: ORIENTATION (FROM 90° TO 180° - TWIST ORIENTATION ANTICLOCKWISE, IF 0° TO 90° - CLOCKWISE).

IP techniques sequence

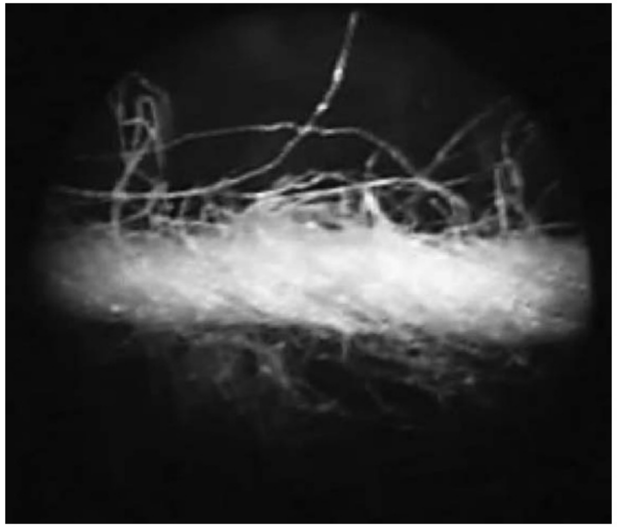


Fig.39 - Initial nonfolded 62tex yarn image

Fig.40 - Algorithm final image

Fibers Twist Orientation in Nonfolded Yarns Application (C)

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Example Results

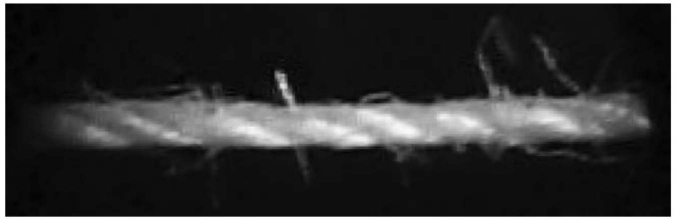


Fig.41 - 22tex yarn image acquired

Fig.42 - 22tex final image (app. A)

Table 8 - Particle analysis results for the 22tex yarn

Particles	First Horizontal Pixel	Orientation (°)	Area (pixels)
1	52	162.9	128
2	88	168.8	145
3	108	161.6	126
4	140	168.0	83

(average distance between particles: 29.3±8.3pixels)

Yarn production characteristics results:

- Fibers twist orientation: clockwise;
- Folded yarn twist orientation: anticlockwise;
- Number of cables: more than one cable (folded yarn);
- Folded yarn twist step: 0.4 ± 0.1mm.

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Example Results

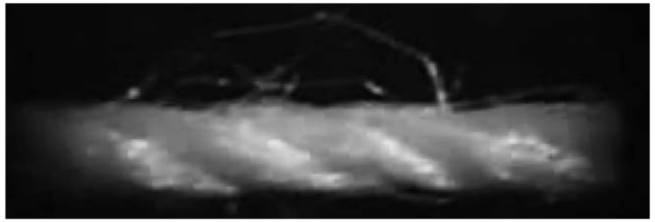


Fig.43 - Image acquisition of a 55tex yarn

Fig.44 - Final image 55tex yarn (app. A)

Table 9 - Particle analysis results for the 55tex yarn

Particles	First Horizontal Pixel	Orientation (°)	Area (pixels)
1	73	154.5	377
2	116	158.0	292
3	181	174.6	120

(average distance between particles: 54±15pixels)

Yarn production characteristics results:

- Fibers twist orientation: clockwise;
- Folded yarn twist orientation: anticlockwise;
- Number of cables: more than one cable (folded yarn);
- Folded yarn twist step: 0.7 ± 0.2mm.

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Example Results

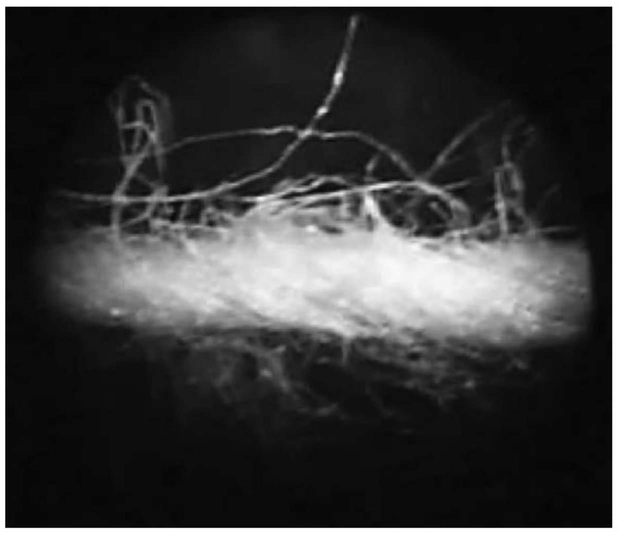


Fig.45 - Initial spun(nonfolded) 62tex yarn image

Fig.46 - 62tex yarn final image (app. A)

Table 10 - Particle analysis results for the 62tex yarn

Particles	First Horizontal Pixel	Orientation (°)	Area (pixels)
1	132	176.6	5527

Yarn production characteristics:

- Fibers twist orientation: anticlockwise;
- Number of cables: one cable - spun (nonfolded) yarn.

(A particle orientation angle of 136º was obtained - app. C)

Fig.40 - Algorithm final image (app. C)

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Example Results

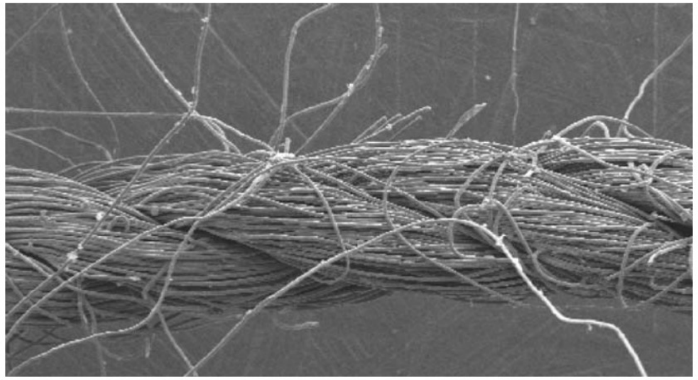


Fig.47 - Electronic microscope image for the 55tex yarn (40X)

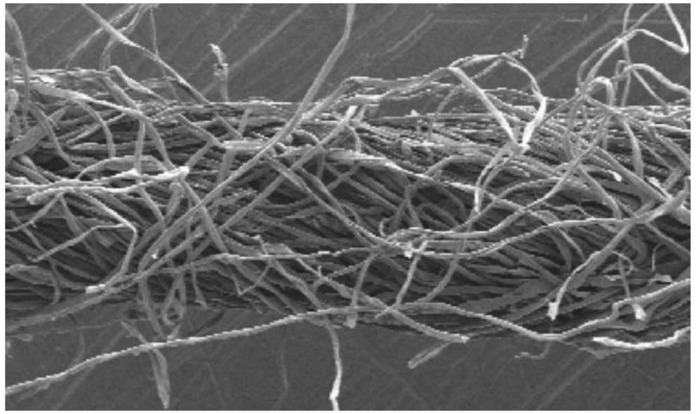


Fig.48 - Electronic microscope image for the 62tex yarn (40X)

Validation results:

- 55tex yarn is a folded yarn, anticlockwise twist orientation, clockwise fibers twist orientation, twist step between 0.64mm and 0.78mm was measured;
- 62tex yarn is a spun(nonfolded) yarn, anticlockwise fibers twist orientation.

Results obtained from the electron microscope images are in agreement with the results obtained with the developed application - **methodology validation**.

YARN PRODUCTION CHARACTERISTICS DETERMINATION USING IMAGE PROCESSING TECHNIQUES (PHASE 4)

Project Achievements – phase 4

- **The methodology used to automatically determine yarn production characteristics yields reliable results as validated with the electronic microscope analysis;**
- A **low-cost image acquisition hardware** using a USB web camera coupled to microscope optics with monochromatic illumination was adequate;
- The developed application with the **IMAQ Vision software** from National Instruments enabled to apply the required image processing techniques and algorithms.

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

- **CONSIDERING THE PREVIOUS STUDIES A PROTOTYPE (YSQ) WAS BUILD INTEGRATING:**
  - OPTICAL AND ELECTRONIC SETUPS TO OBTAIN THE MEASUREMENTS OF YARN HAIRINESS, YARN DIAMETER AND MASS VARIATION;
  - EXTERNAL MODULE TO OBTAIN THE YARN PRODUCTION CHARACTERISTICS WITH IMAGE PROCESSING.

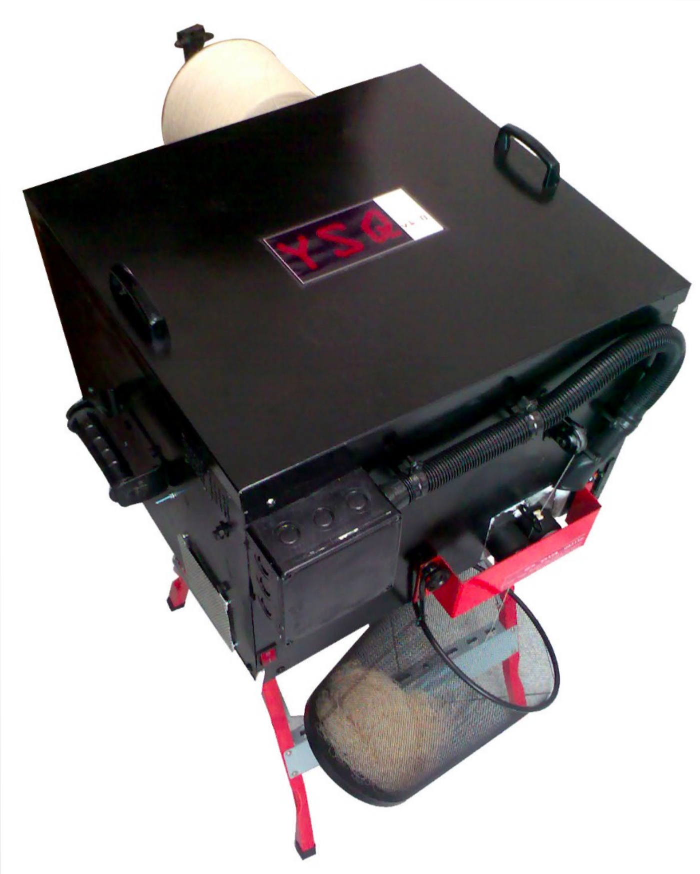


Fig.49 - YSQ prototype

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

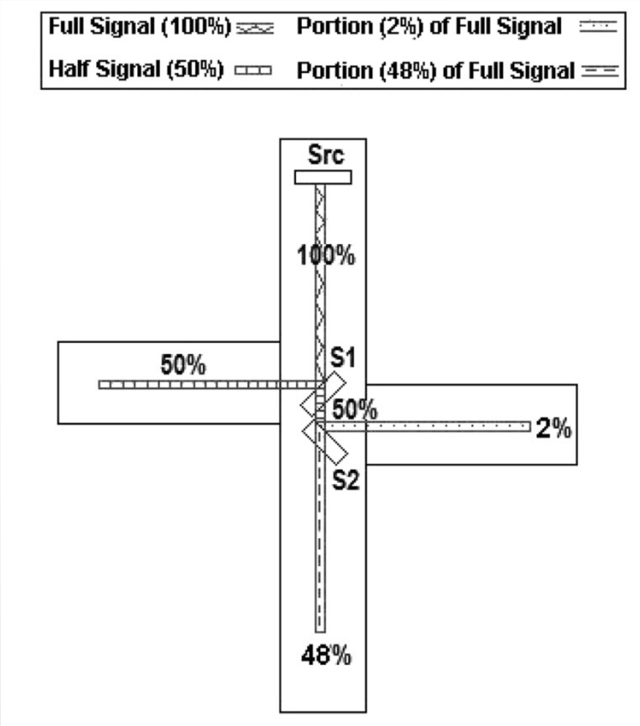


Fig.50 - YSQ laser beam split configuration

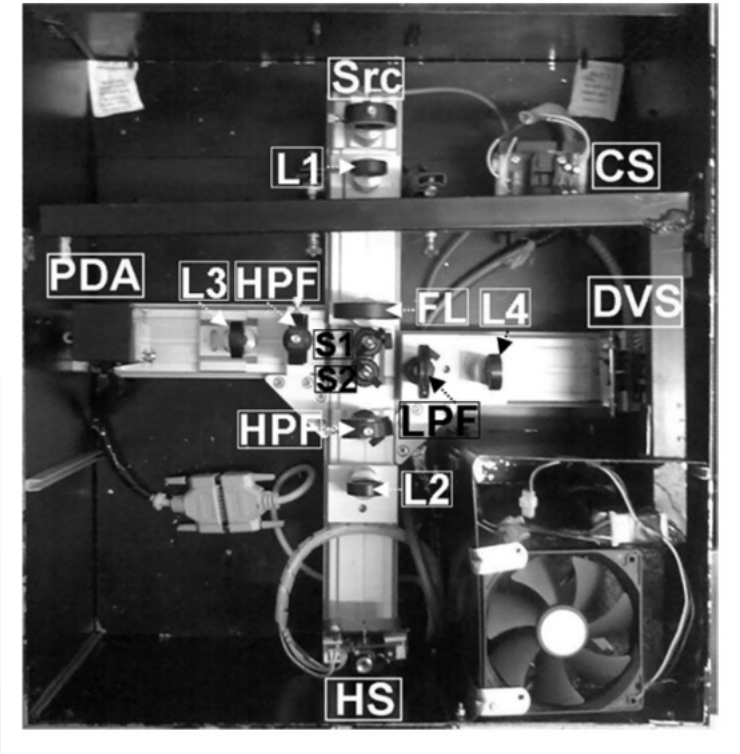


Fig.51 - YSQ optical and capacitive sensors hardware

Fig.56 - Image plan of lenses L2 and L3 (HPF)

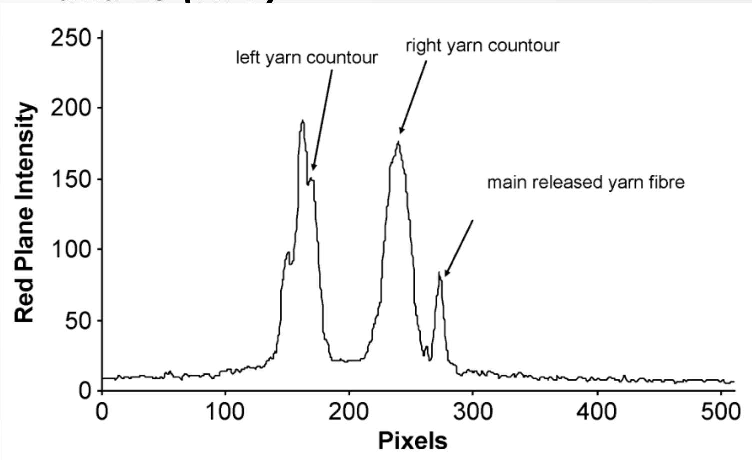


Fig.52 - Line profile analysis of selected region

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

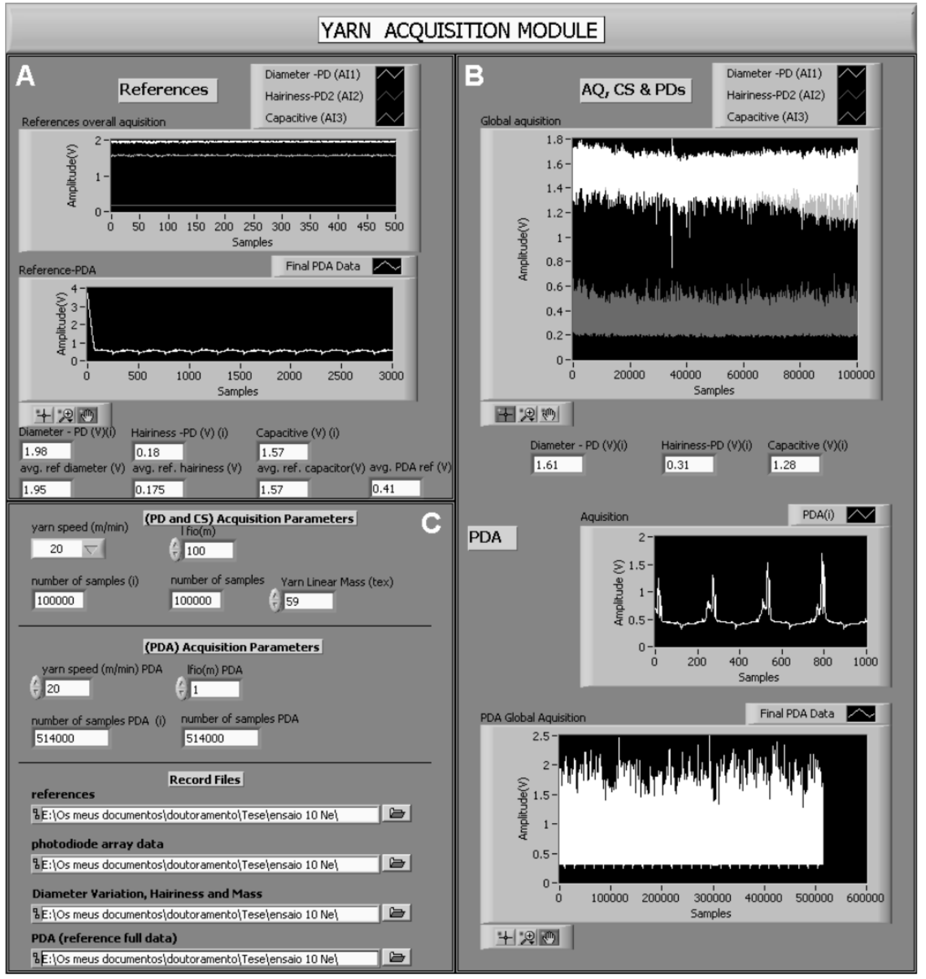


Fig.53 - Front panel of the yarn acquisition software module

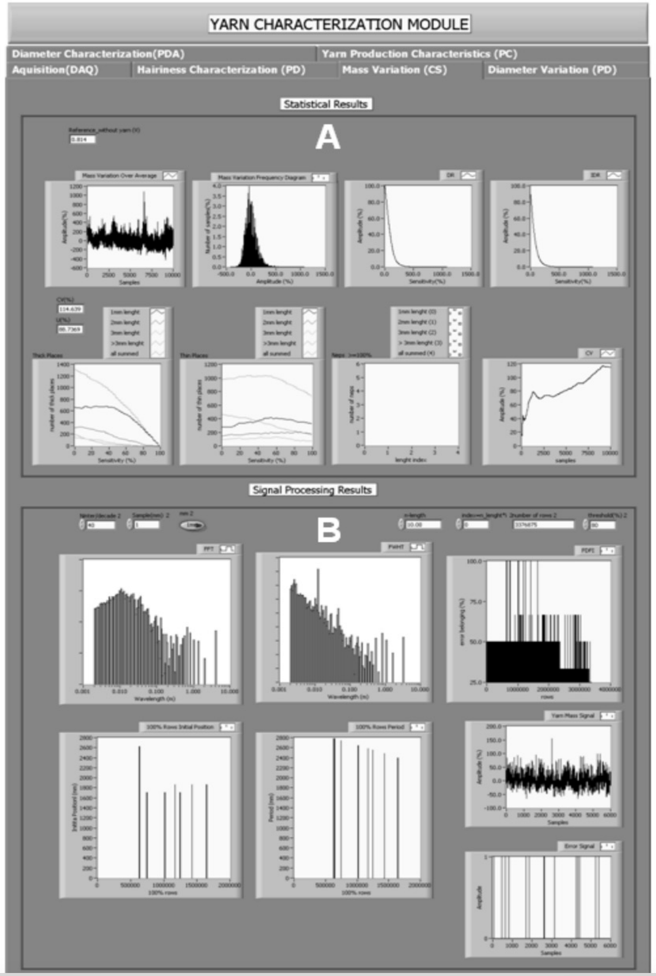


Fig.54 - Front panel of the yarn characterization software module

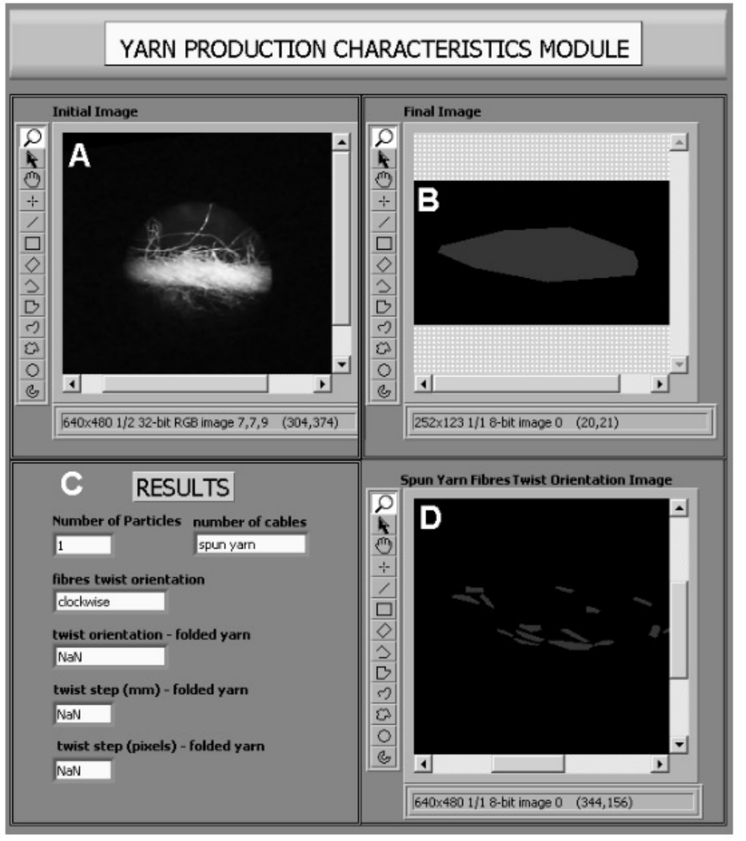


Fig.55 - Front panel of the yarn production characteristics software module

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

- **TEST COMPARISON BETWEEN YSQ AND USTER TESTER 3 FOR THE 100% COTTON YARN OF 59TEX (1KM LENGTH) – STATISTICAL RESULTS AND IRREGULARITIES**

Table 11 - Parameters results

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

Table 12 - Results of absolute variation

Parameter	Absolute variation (b - a)
U (%)	+ 4.28
CV (%)	+ 5.70
Thin Places (-50 %) / km	+ 1343
Thick Places (+50 %) / km	+ 7311
Neps (>= +200 %) / km	+ 238
H	- 6.75
sH	+ 0.17

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

- **TEST COMPARISON BETWEEN YSQ AND USTER TESTER 3 FOR THE 100% COTTON YARN OF 59TEX (1KM LENGTH) – SIGNAL PROCESSING RESULTS – MASS VARIATION**

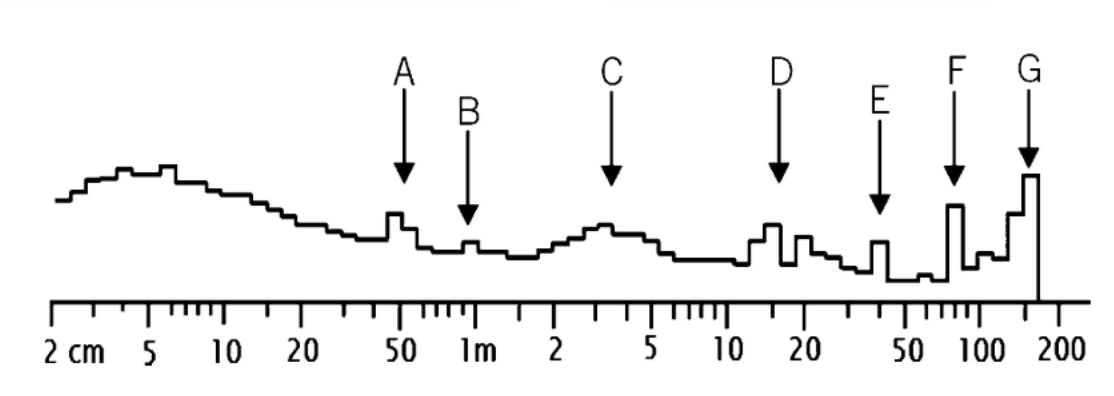


Fig.56 - Uster Tester 3 mass variation spectrogram

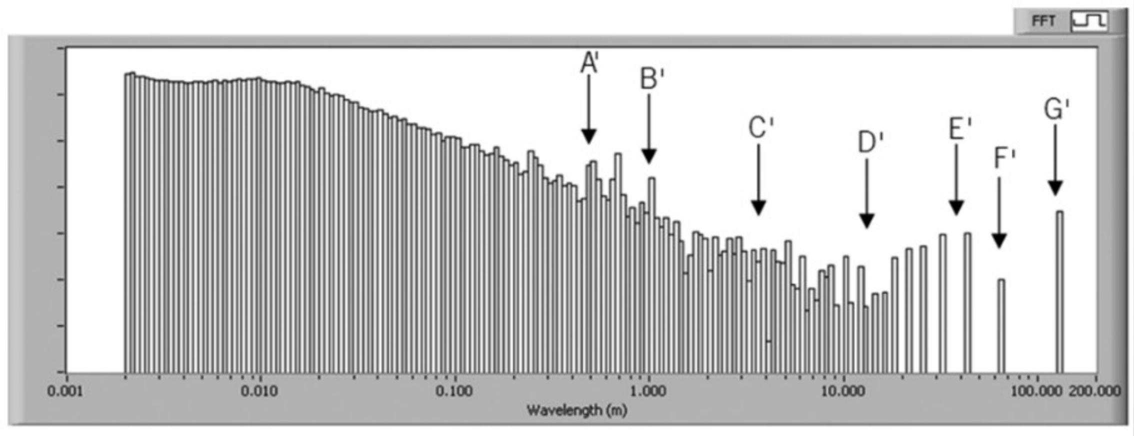


Fig.57 - YSQ mass variation spectrogram

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

- **TEST COMPARISON BETWEEN YSQ AND USTER TESTER 3 FOR THE 100% COTTON YARN OF 59TEX (1KM LENGTH) – SIGNAL PROCESSING RESULTS – HAIRINESS VARIATION**

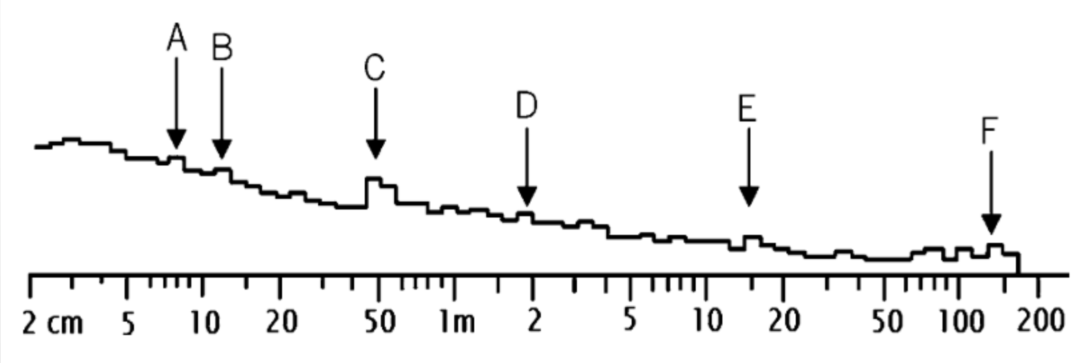


Fig.58 - Uster Tester 3 hairiness variation spectrogram

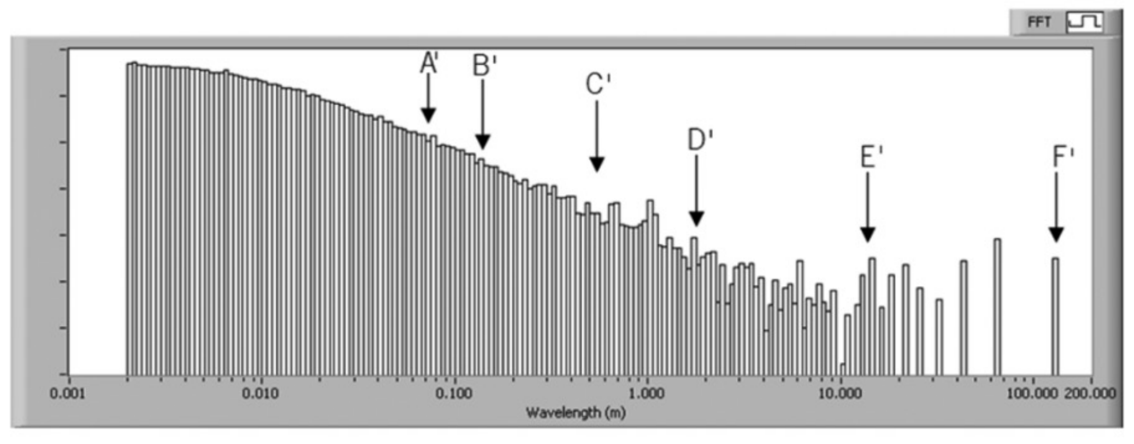


Fig.59 - YSQ hairiness variation spectrogram

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

Project Achievements – phase 5

- **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;
  - integration and measurement of yarn mass variation based on 1mm capacitive sensor enabling the direct detection of nep irregularities;

YARN SYSTEM QUALITY (YSQ) PROTOTYPE (PHASE 5)

Project Achievements – phase 5 (cont.)

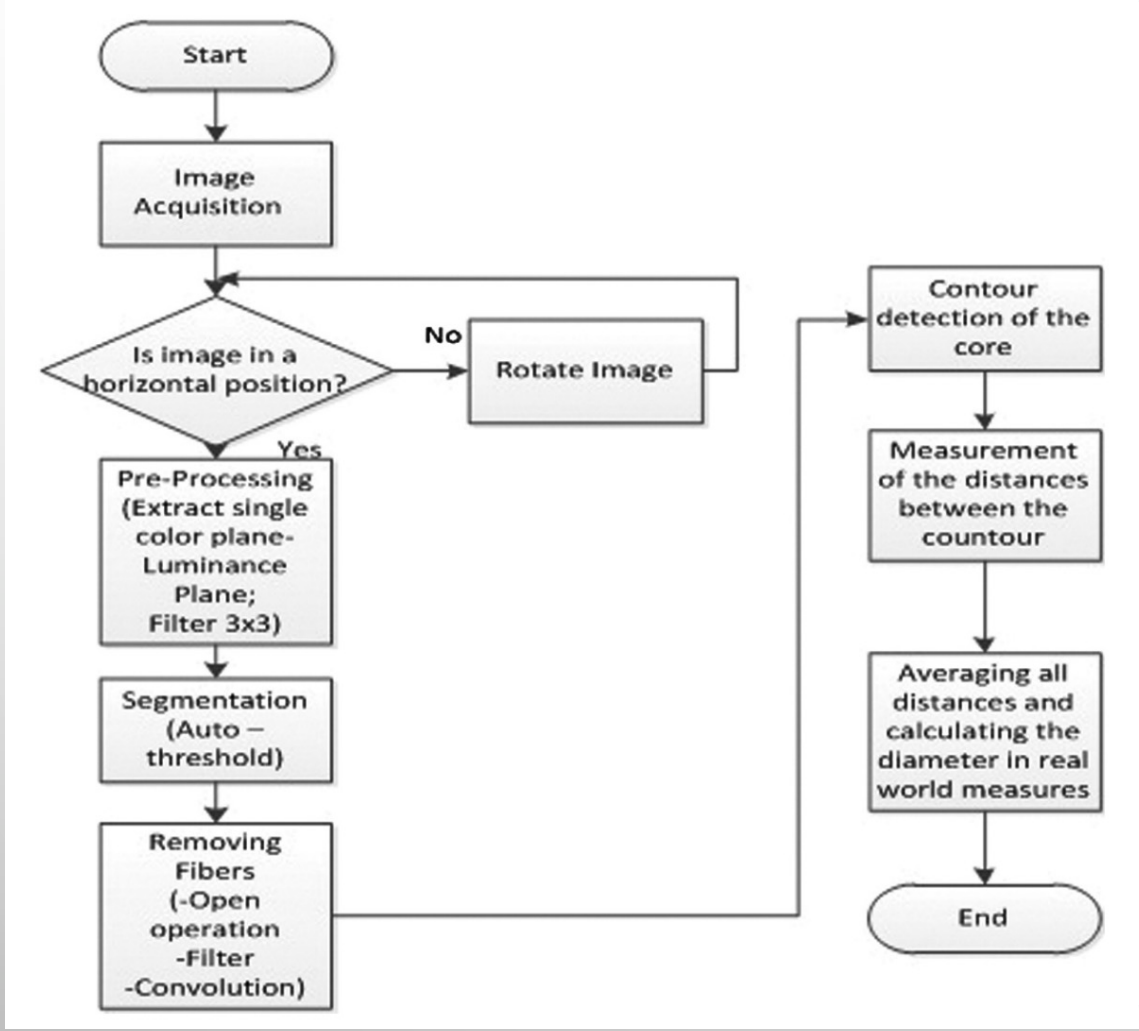
- determination of new parameters in yarn analysis allowing a high precise yarn characterization;
- use of three signal processing techniques, enabling an accurate periodical errors characterization;
- automatic determination of yarn production characteristics.

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

After the development of the YSQ, the project team dedicated its efforts to developed solutions to obtain yarn parameters using image processing:

- motivated by the computational effort cost reduction and fast computational resources;
- to automatically characterize yarn diameter, hairiness and irregularities (yarn in a stationary state);
- identify and quantify the loop and protruding fibers (hairiness).

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

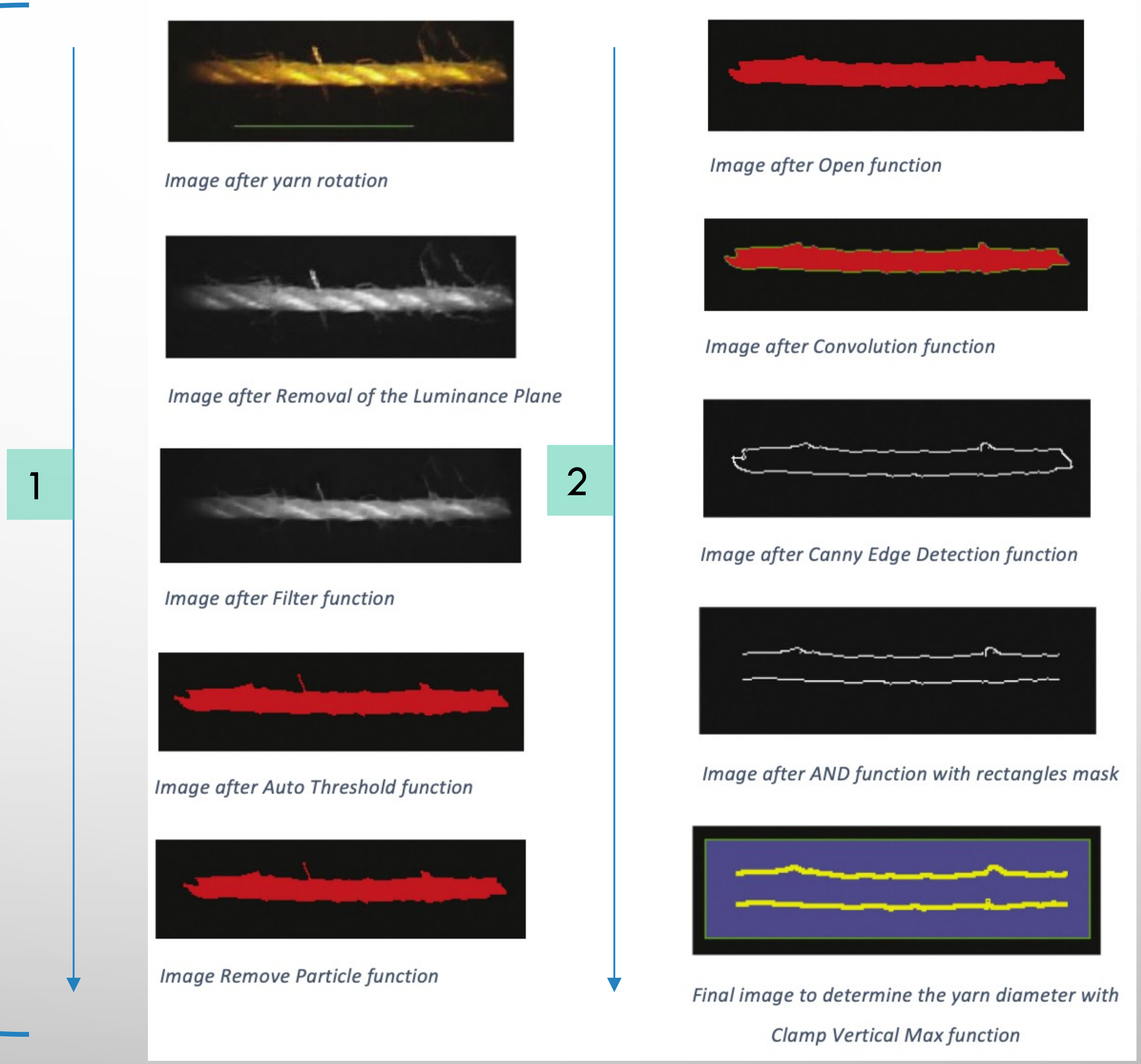


Diameter determination flowchart

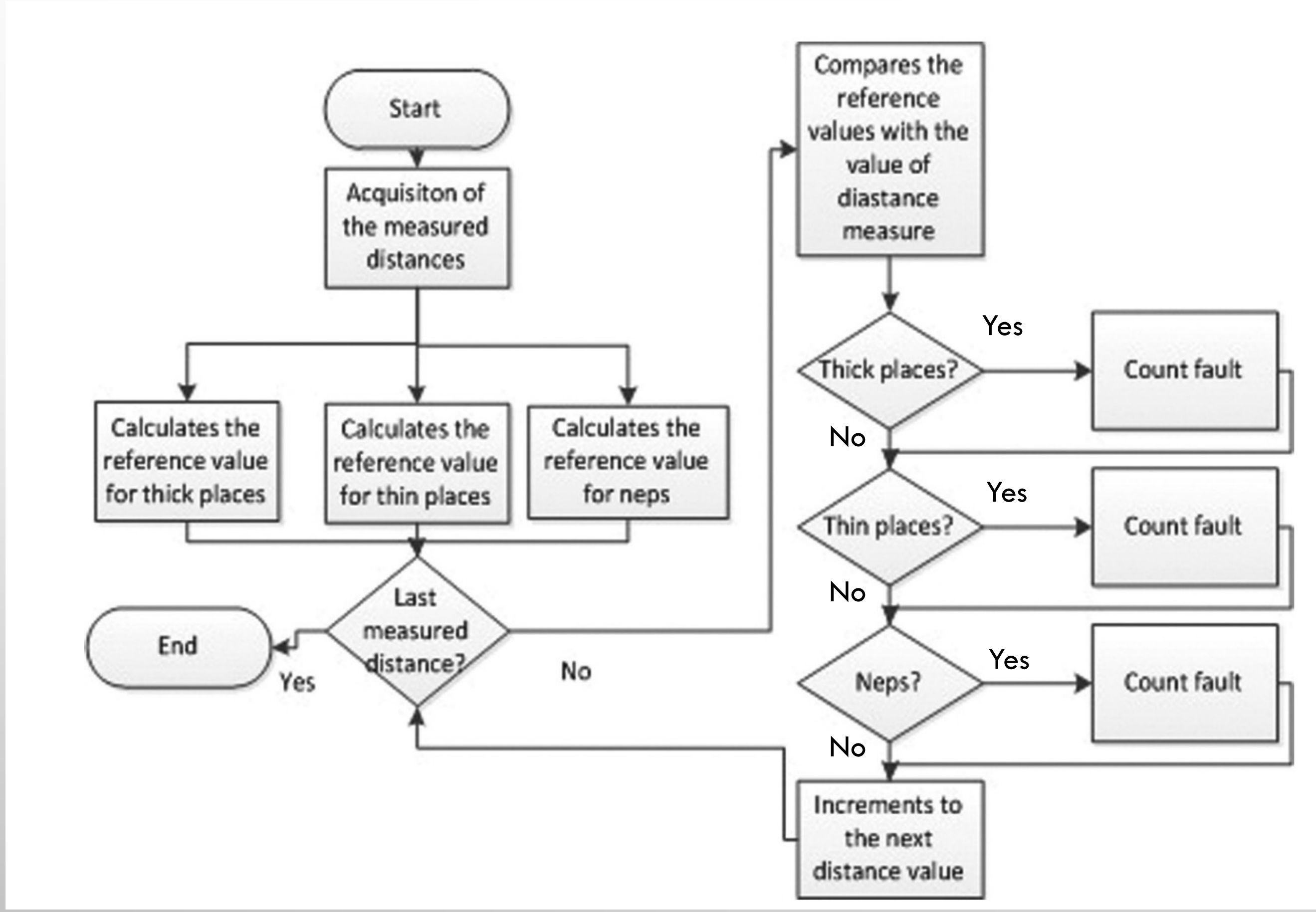
YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

Example of application of the diameter determination algorithm:

Fig.60 - Initial image acquisition of a 22tex yarn



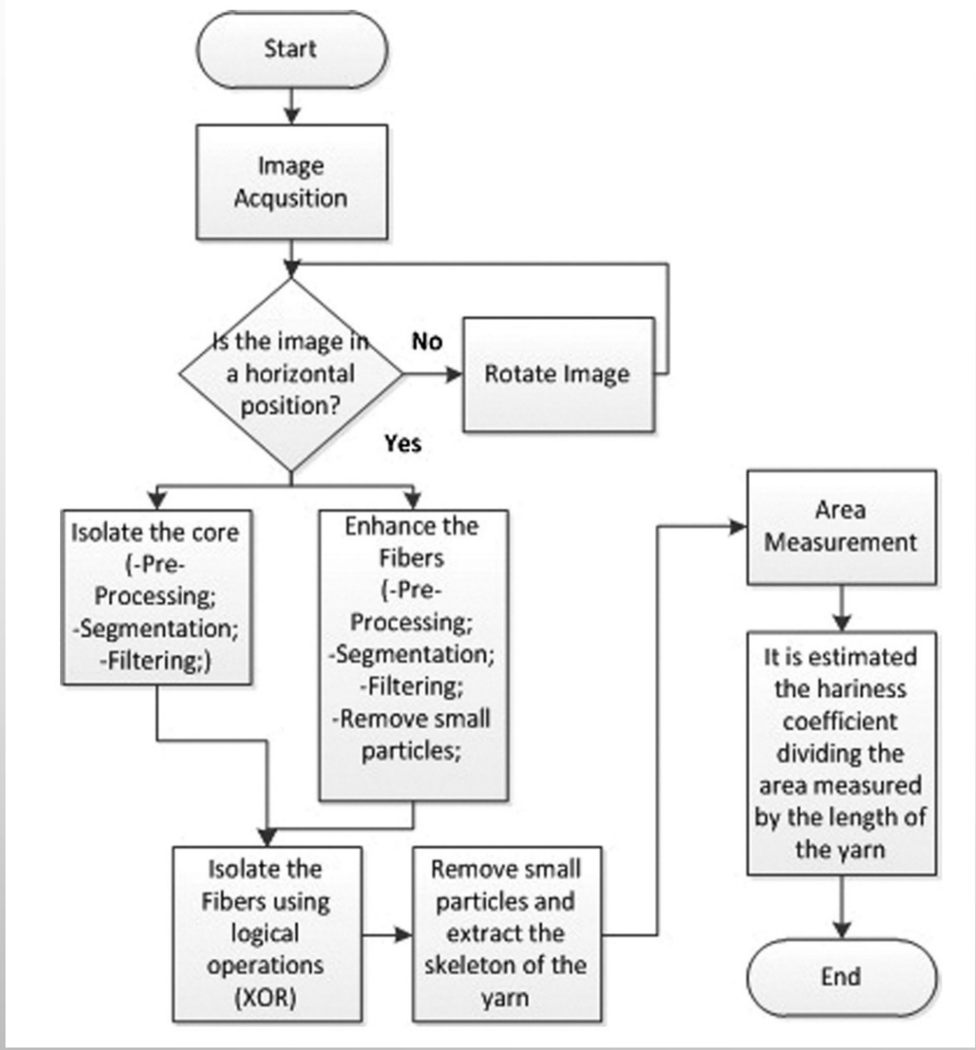
YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)



Irregularities determination flowchart

[d(mm)=4,44x10^{-2}*√(tex/*p*)]

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)



Hairiness determination algorithm flowchart

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

Example of application of the hairiness determination algorithm:

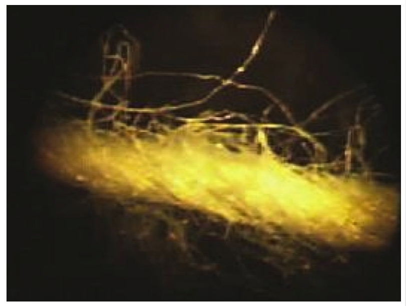
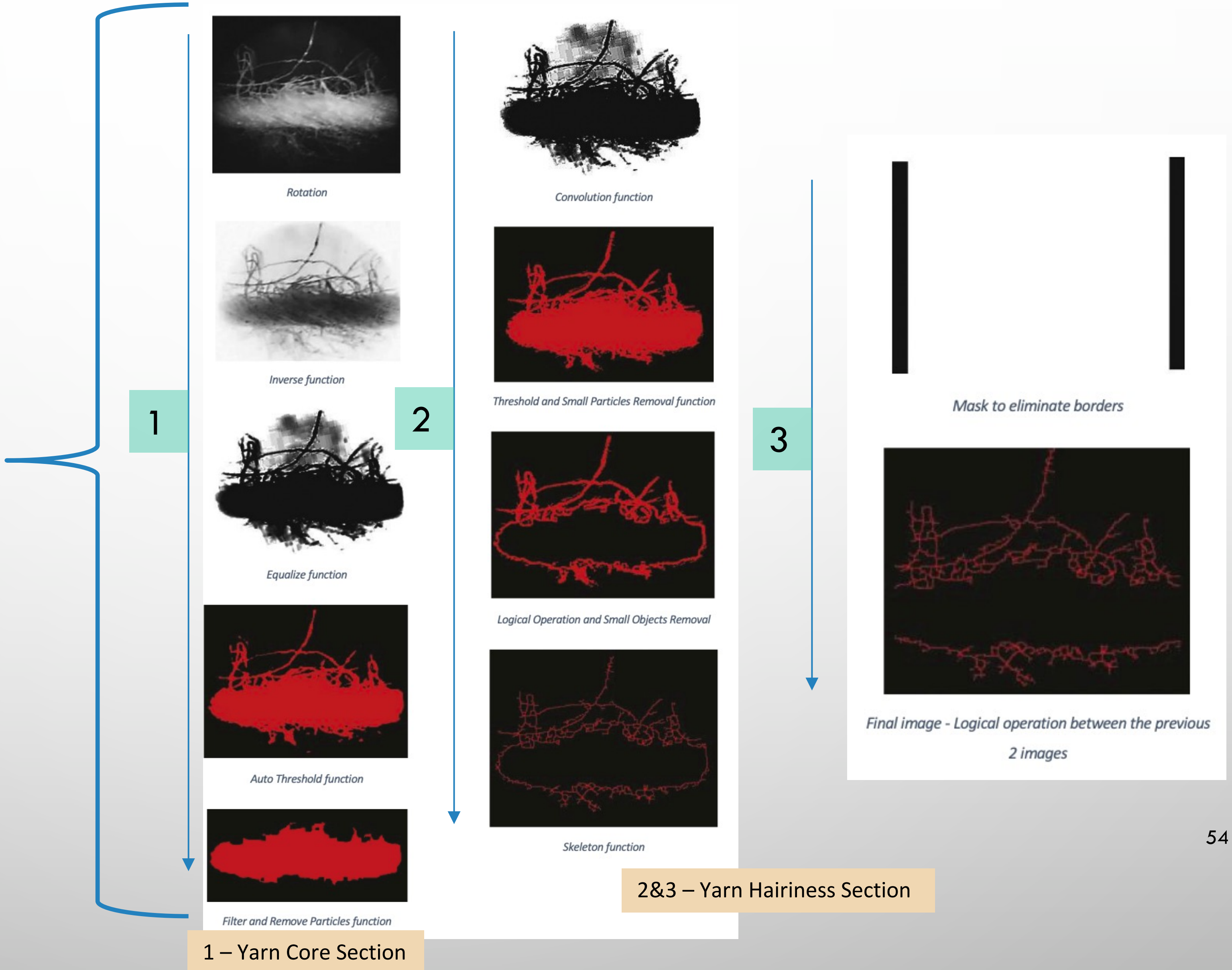
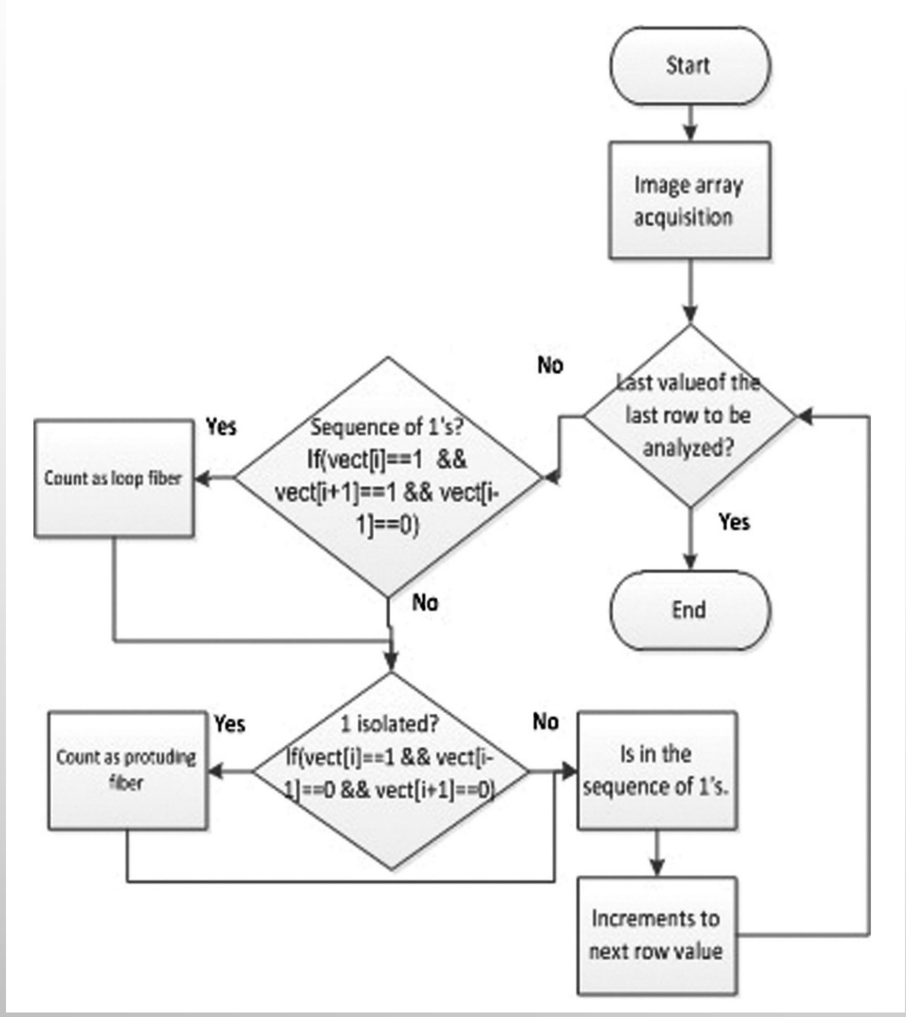


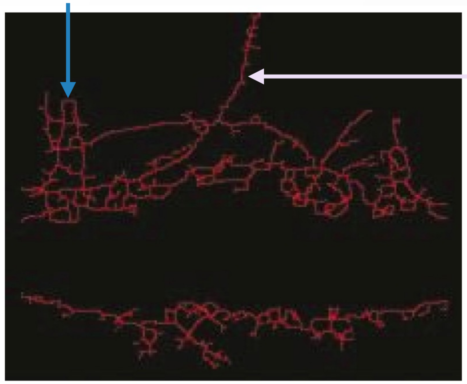
Fig.61 - Initial sample image acquisition of a 62tex yarn



YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)



Loop fiber



Protruding fiber

Flowchart of the loop and protruding fibers distinction algorithm

loop fibers - sequence of 1’s pixels in the same row;

protruding fibers - sequence of 1’s pixels in the same column.

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

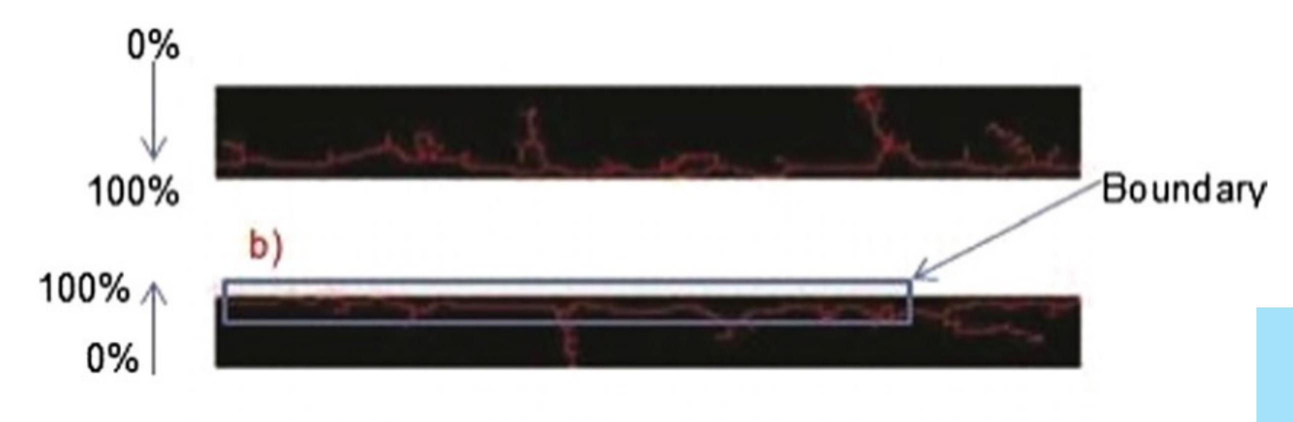


Fig.62 - Loop/protruding fibers detection - 22tex yarn

Loop/protruding fibers detection/distinction Results

Table 13 - Loop/protruding fibers detection – 22tex yarn

	10%	40%	50%	80%	100%
Loop	0	0	8	105	20
Protruding	0	2	7	1	1

More feasible analysis

Boundary between hairiness/yarn contour

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

Diameter Results

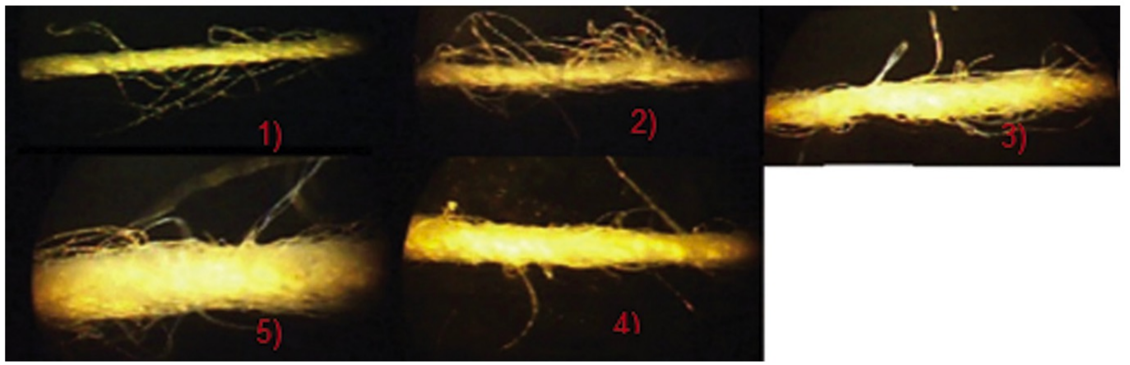


Fig.63 - Yarn acquired images: (1) 16.4tex, (2) 19.68tex, (3) 29.5tex, (4) 36.9tex, (5) 98tex

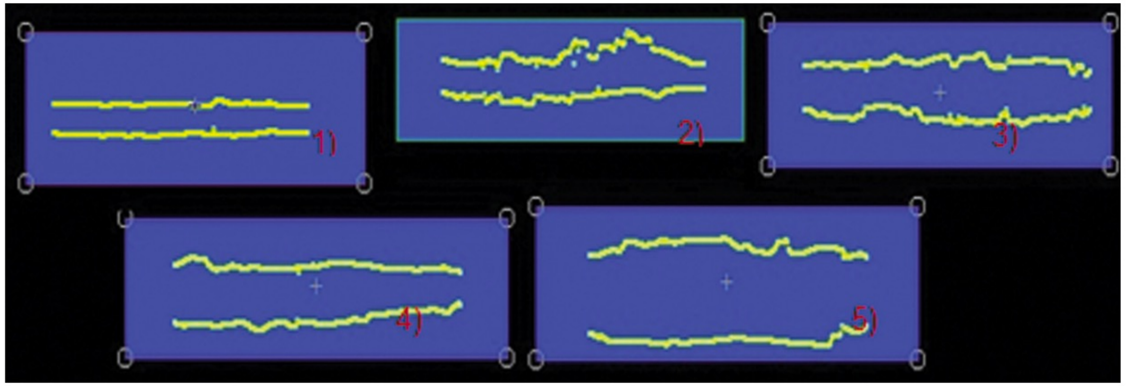


Fig.64 - Yarn images after the image processing techniques application to diameter determination: (1) 16.4tex, (2) 19.68tex, (3) 29.5tex, (4) 36.9tex, (5) 98tex

Table 14 - Diameter determination comparison between experimental (10 places) and empirical values for each yarn (sample number)

Sample number	Linear mass (Tex)	Average d_p (pixels)	d_t (mm)	Average d_e (mm)	Standard deviation (mm)	Relative error (%)
1	16.40	16.70	0.2430	0.2288	0.017	6.2
2	19.68	20.99	0.2662	0.2875	0.097	7.4
3	29.50	24.84	0.3259	0.3402	0.042	4.2
4	36.90	29.62	0.3645	0.4058	0.027	10.2
5	98.00	52.62	0.5939	0.7209	0.055	17.6
					Average error	9.1%

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

Irregularities Results

Table 15 - Yarn irregularities for the 19.68tex yarn (2)

Sample number	Thick places	Thin places	Neps
1	0	0	0
2	0	0	0
3	2	0	0
4	0	0	0
5	0	0	0
6	2	1	0
7	4	1	0
8	0	0	0
9	0	0	0
10	2	0	0

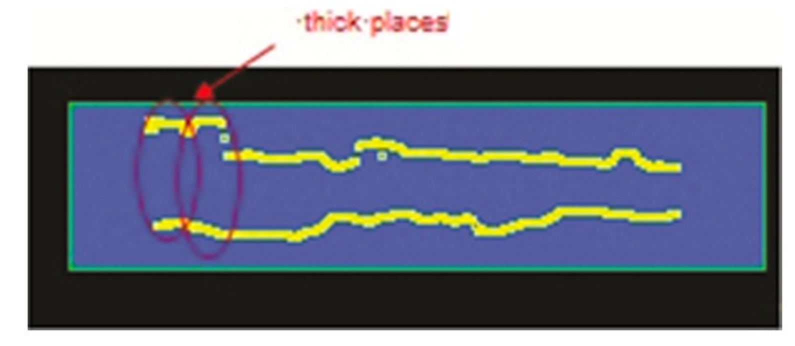


Fig.65 - Sample 3 thick places of the 19.68tex yarn

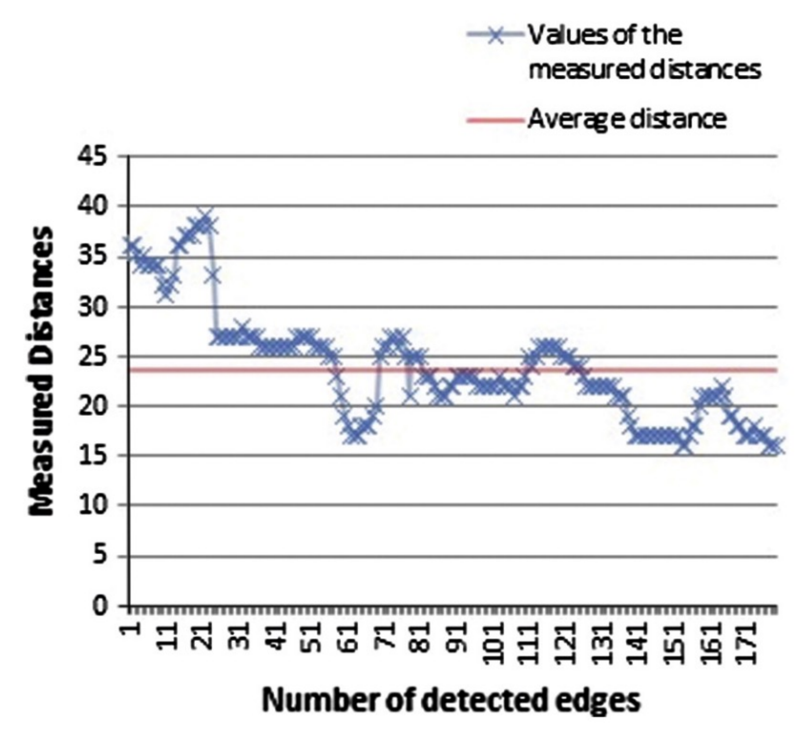


Fig.66 - Pixels diameter variation over the 19.68tex yarn – sample 3

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

Hairiness Results

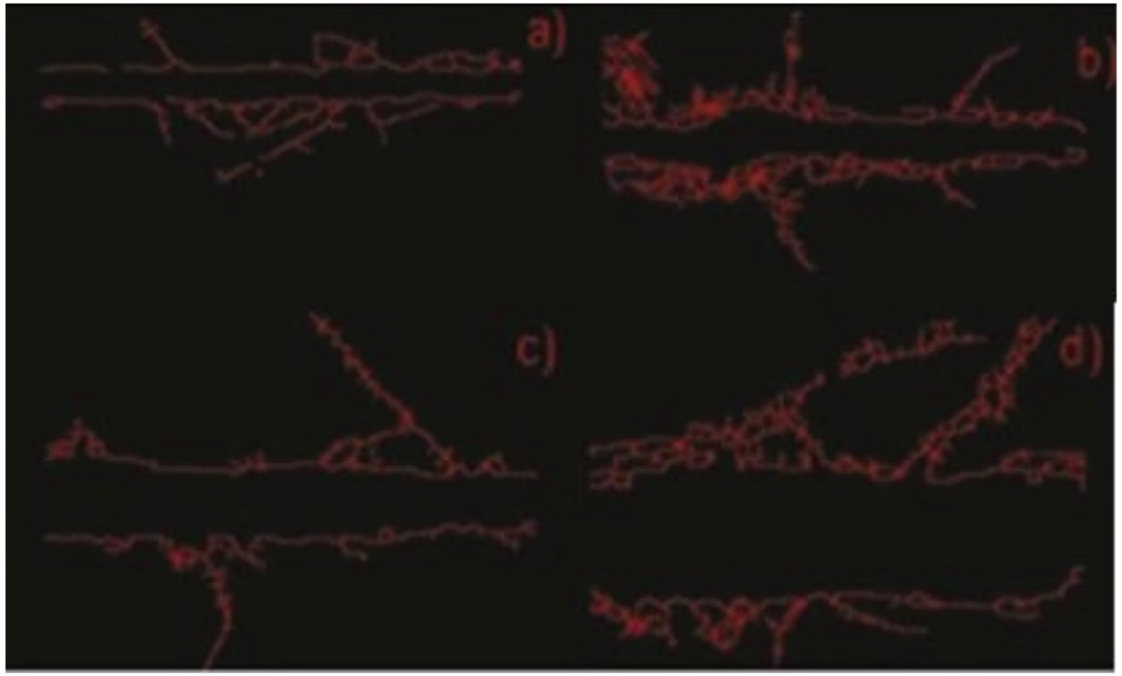


Fig.67 - Yarn images after the image processing techniques applied to hairiness determination: (a) 16.4tex, (b) 19.68tex, (c) 36.9tex, (d) 98tex

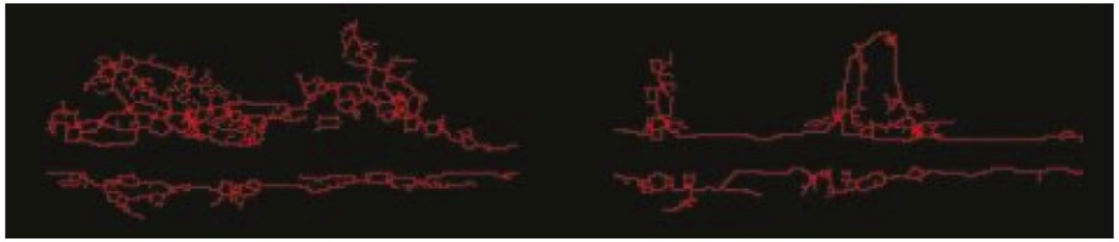


Fig.68 - Example of 2 samples of the 19.68tex yarn

Table 16 - Hairiness results (10 samples) comparison between Uster Tester 3 and the presented methodology

Sample number	Linear mass (Tex)	H_u (m/m)	Average H_e (m/m)	Relative error (%)
1	16.40	4.69	4.31	8.8
2	19.68	7.08	6.69	5.8
3	36.90	4.37	4.56	4.2
4	98.00	7.18	7.15	0.4
			Average error	4.8%

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

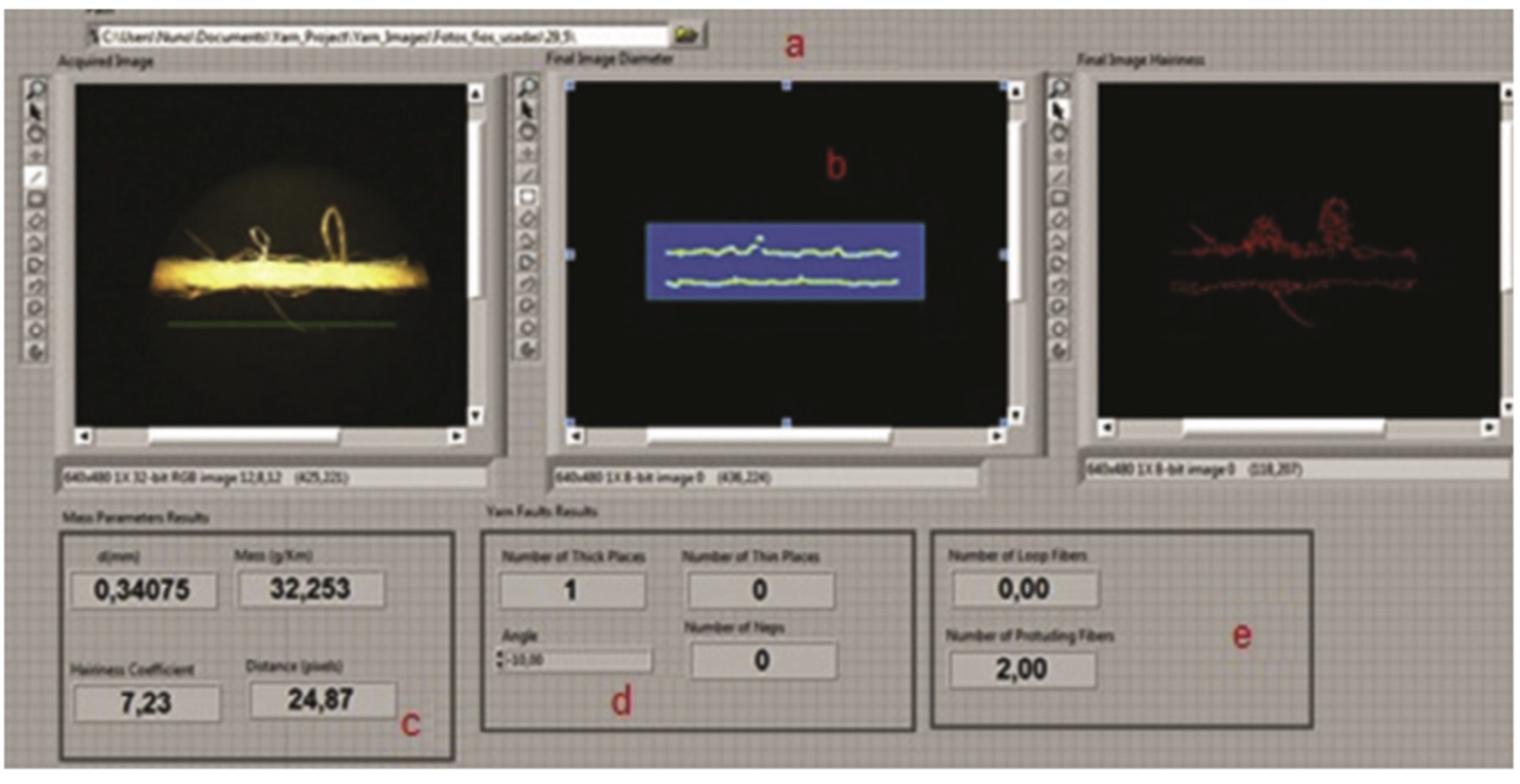


Fig.69 - Front panel of the developed user interface

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

- **ADDITIONAL STUDIES**
  - CONSIDERS THE DEVELOPMENT OF A PROTOTYPE ABLE TO PERFORM ONLINE ANALYSIS USING IMAGE PROCESSING – YSQ–IP (V1).

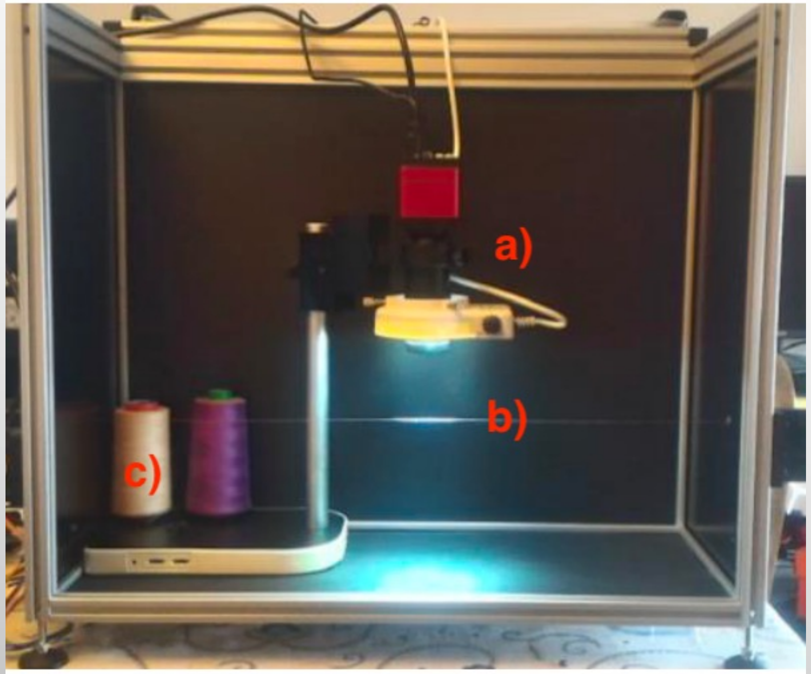


Fig.70 - YSQ-IP (v1): a) image acquisition hardware, b) yarn, c) yarn bobbin

Fig.71 - Image acquisition hardware

Low-cost HDMI VGA Industrial Microscope Camera:
- 13MP;
- 60f/s;
- 130x lens;
- led illumination.

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

- **YSQ–IP (V1):**
  - YARN SPEED OF 0.01M/S (ONLINE ANALYSIS);
  - IMAGE PROCESSING ALGORITHMS DEVELOPED/OPTIMIZED WITH THE OPENCV LIBRARY.

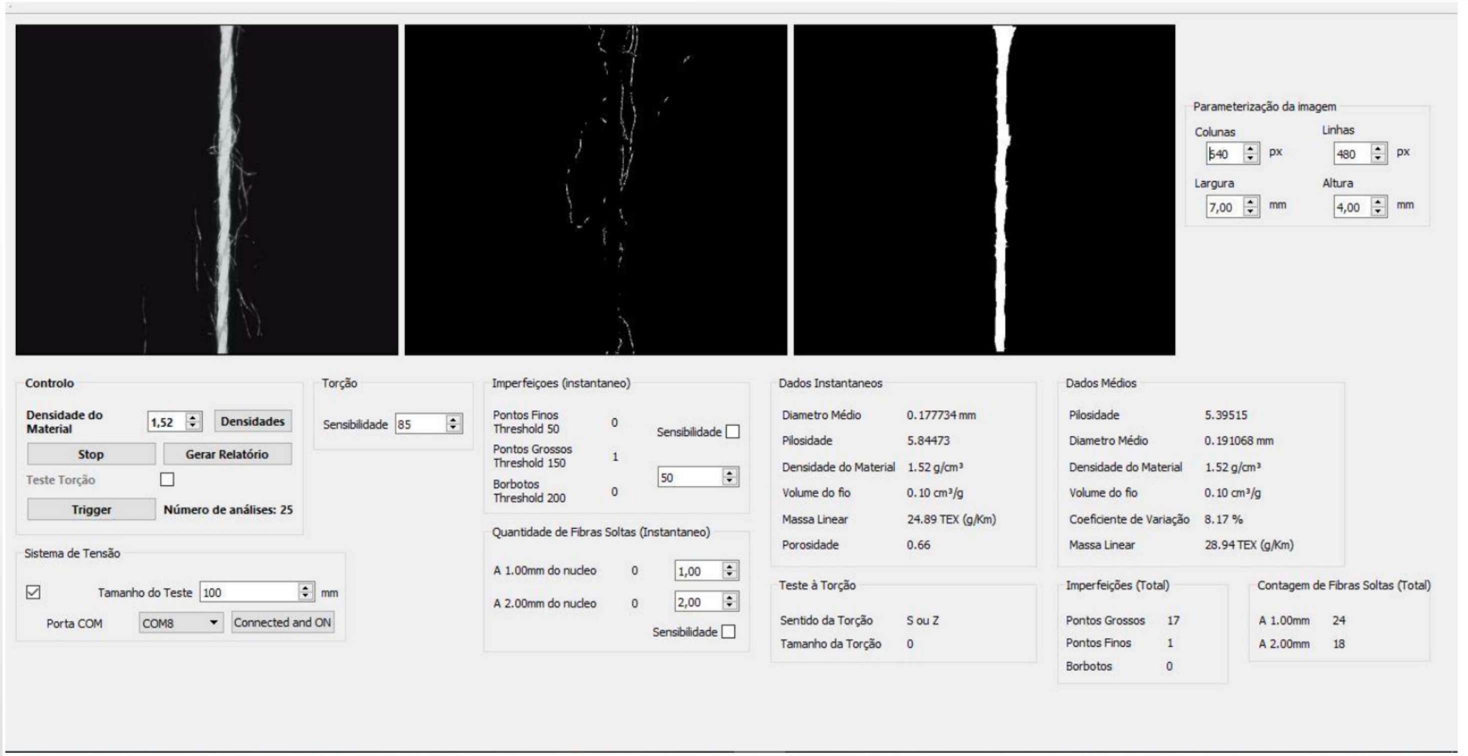


Fig.72 - YSQ – IP (v1) online system interface

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

YSQ–IP (v1): 24,89tex yarn image acquisition and processing example

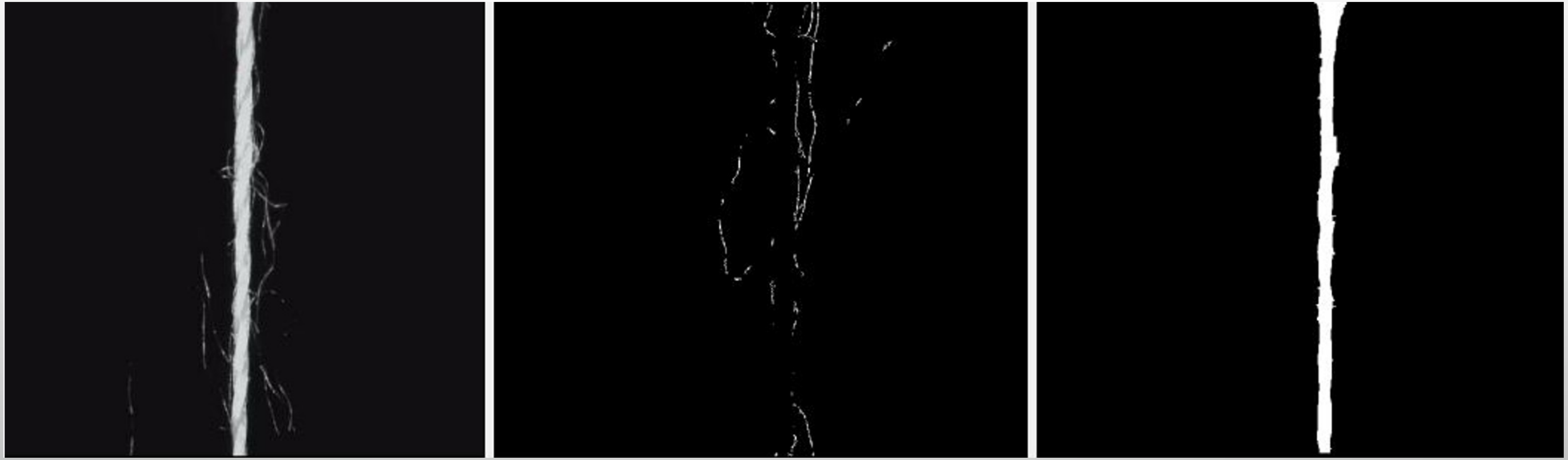


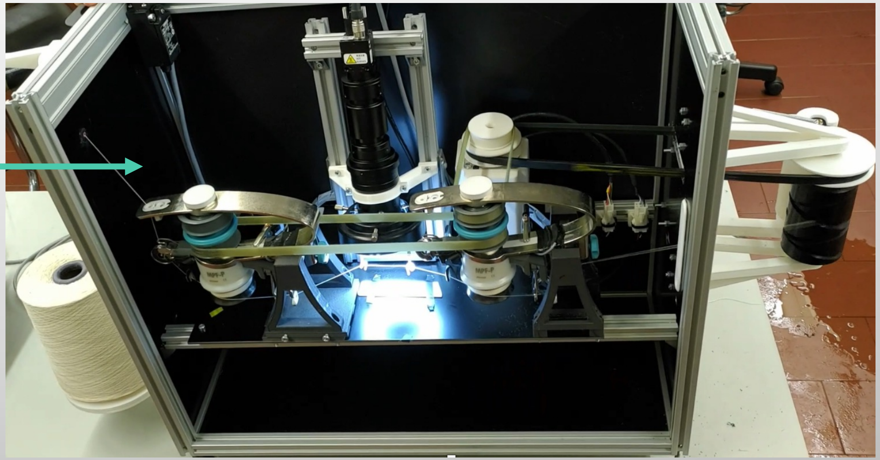
Fig.73 - YSQ – IP (v1) yarn acquisition and processing

a) Acquired image *b) Hairiness component* *c) Yarn core component*

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

- **UNDERGOING STUDIES**
  - **YSQ–IP (V2):**
    - INTEGRATED HMI – PROTOTYPE PARAMETERIZATION AND OPERATION;
    - ENHANCED IMAGE ACQUISITION HARDWARE;
    - INTEGRATED YARN CLOSED LOOP SYSTEM – MULTIPLE SAMPLE TESTS.

YSQ-IP (v2)



YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

Project Achievements – phase 6

- **The methodology using image processing yarn to automatically determine yarn parameters (linear mass, diameter, hairiness and irregularities) seems adequate;**
- The **preliminary study** for the detection and distinction between loop and protruding fibres reveal to be a positive indicator for this analysis, but with a considerable margin of error, which leads to the need for a thorough study on the optimization of the methodology.

YARN PARAMETERS DETERMINATION USING IMAGE PROCESSING (PHASE 6)

The study of the hairiness spatial yarn position based on yarn hairiness measurements.

The development of a method with an electric field to place yarn loosen fibers (hairiness) fully straight and accurately determine the length of yarn hairs.

YSQ-IP (v2) Challenges

The improvement of methods to detect and distinguish between the hairiness loop and protruding fibers supported by artificial intelligence algorithms.

Use of artificial intelligence techniques to predict the fabrics (woven/knitting) quality as a result of yarn parameters determination.

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IARIA

DEVELOPMENT OF AN AUTOMATIC YARN CHARACTERIZATION SYSTEM

VÍTOR CARVALHO *ET AL.*

Thank you!

ESCOLA SUPERIOR DE TECNOLOGIA

IPCA INSTITUTO POLITÉCNICO DO CÁVADO E DO AVE

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