Quality testing of staple yarn by an instrument with dual sensing and its comparative study with capacitive sensing

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An instrument employing both image processing and optical sensing in a single run has been developed to evaluate yarn quality parameters such as irregularity, imperfections and hairiness. Dedicated software, inbuilt within the system, is also developed, which measures the attributes from both the sensors, and a best fit representation is made. The irregularity and imperfections obtained from proposed instrument are compared with those obtained from universally accepted capacitive sensing Uster tester, whereas hairs/meter are compared with Zweigle tester. The cotton, cotton-polyester blended and jute yarns have been tested in all the systems. The repeatability and reliability of results in both image processing and optical sensing are found insignificant in 5% confidence level. It is observed that the yarns with diameter value up to 0.65 mm can be evaluated by optical sensor, but above this threshold, image processing may be done successfully. Uster tester result mostly corroborates with image processing. Optical sensor shows higher values than image processing.

1 Introduction

The basic short term quality parameters for yarn are irregularity, imperfections and hairiness. Irregularity or unevenness is the estimate to judge variations along a yarn. Imperfections means the number of thin and thick places and hairiness denotes the number of protruded fibres along the yarn. So for ensuring the quality of the yarn a testing instrument for yarn is necessary which can quantify those parameters for a part of the yarn.

The universally accepted sensing method of the yarn evenness tester is the capacitance type. In such instrument, yarn passes through the parallel plate capacitor which senses the short term mass variation of yarn and produces a change of mass in a plotter. Carvalho *et al.*[1] and Pinto *et al.*[2] tried to eliminate both the problems by increasing the resolution by eight times and compensation technique to deal with the change of humidity. They also incorporated some new parameters such as Integral Deviation Rate (IDR), Fast Fourier Transform (FFT) based analysis, Deviation Rate (DR) and Spectrogram to characterise the yarn. They carried out the experiments with

Fourier optics for hairiness detection of the yarn. To eliminate the influence of the hairiness in the diameter they carried out a comparative study[3-5], considering the yarn mass and diameter in 1 mm resolution. A statistical correlation has been inferred regarding the mass and diameter which makes it possible to convert diameter to mass and vice versa. They developed yarn system quality (YSQ) where simultaneously yarn hairiness, mass, irregularity and diameter can be measured[6-8]. Using coherent optical signal processing based on a single photodiode, the same team was able to quantify yarn irregularities associated with diameter variations that could be linearly correlated with mass variation [9]. With the advent of image processing, effort has been made by Guha *et al.*[10] with static image for finding out the hairiness related parameters such as hair area and hair length index. Kuzanski[11, 12] reviewed most important measurement methods applied to determine yarn attributes and proposed automatic computer method of yarn image processing and analysis. Carvalho *et al.*[13] presented idea to automatically quantify yarn production characteristics like snarl length, number of cables, fibre orientation and cable orientation. In the work of Fabijanska[14], popular thresholding methods are reviewed and tested on images presenting yarn of

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different hairiness. Fabijanska and Strumillo[15] developed image analysis algorithm for quantifying yarn hairiness by two measures like hair area index and hair length index. Sengupta et al.[16] and Roy et al.[17-19] developed a low cost yarn parameterisation unit by image processing.

The major disadvantage of the capacitive method is that it can measure the yarn at a resolution of 8 mm but the imperfections may occur at level much lower than 8 mm. Another drawback of the conventional tester is that it depends on the humidity and the change in ambient temperature which is prone to erroneous value.

With an intension of more precise characterization unit, in this study a multi sensing technology has been attempted in a new device with photo transistor and web camera by optical means as well as by imaging simultaneously. Image processing is a slower process but with higher accuracy and is judiciously chosen for the way of measuring of shorter length of yarn. On the other hand, to measure the longer length with moderate accuracy, optical method is used. Apart from this, as yarns are visible through camera, the relative fibre orientation and twist of yarn are judged qualitatively by imaging technique.

2 Theoretical Consideration

Variation in yarn mass changes the capacitance, which gives the mean absolute deviation (U %) and coefficient of variation (CV %) [20], as shown below :

$$U \% = \frac{100}{\bar{X}T} \int_0^T |X_i - \bar{X}| \, dt \qquad \qquad ... (1)$$

where X_i is the Instantaneous value of mass; $\bar{X}$, the Average mass during evaluation time; and T, the evaluation time.

The U% is directly proportional to the mass variation around the average and is independent of the evaluation time. In the developed instrument, primarily the diameter is measured using image processing and optical sensor, giving the mean absolute deviation in terms of diameter as U_d %, as shown below:

$$U_d\% = \frac{100}{\bar{D}T} \int_0^T |D_i - \bar{D}| \, dt \qquad \qquad ... (2)$$

where D_i = instantaneous value of diameter; $\bar{D}$ the average diameter during evaluation time; and T the evaluation time.The CV% in conventional instrument is determined using the following relationship:

$$CV\% = \frac{100}{\bar{X}} \sqrt{\frac{1}{T} \int_0^T (X_i - \bar{X})^2 \, dt} \qquad \qquad ... (3)$$

Similar to Eq.(2), CV_d % in terms of diameter can be expressed as

$$CV_d\% = \frac{100}{\bar{D}} \sqrt{\frac{1}{T} \int_0^T (D_i - \bar{D})^2 \, dt} \qquad \qquad ... (4)$$

The diameter and the mass of the yarn are theoretically correlated as

$$d(mm) = \sqrt{4 \times tex/(\pi \times 10^5 \times \emptyset \times \rho)} \qquad ... (5)$$

where $\emptyset$ represents the yarn porosity; ρ represents the density of the yarn; and tex is mass of yarn in gram per kilometre length. For conversion of diameter in to mass, the yarn is considered as a cylindrical shaped object. Now from known tex value and diameter as calculated from the instrument, the value of constant k can be evaluated as

$$d(mm) = k\sqrt{tex} \qquad \qquad ... (6)$$

Theoretically the value of k is 0.037 which is found 62% lower than that obtained experimentally[4]. Other testing parameters that play important roles in defining the yarn quality are yarn imperfections like thick places (defined as the increase in diameter, usually 50% i.e. 1.5 times of mean diameter and lasting up to 4 mm), thin places (defined as 50% decrease in diameter during a short length up to 4 mm) and neps (defined as huge increase in yarn diameter usually more than 200% for very short length typically from 1 to 2 mm). The threshold for thick/thin places may vary from 30% to 100% more or less as that of average diameter depending on user's choice.

Hairiness of a yarn is the amount of the released fibres from the core of yarn. Presence of long hairs in yarn is considered a drawback in respect of comfort but short hairs sometimes enhance the comfort of the fabric. Surface friction, pilling tendency, tendency of needle and yarn breakage in knitting[19] are affected by the hairiness of the yarn. Therefore, hairiness of the yarn is also important in determining the quality and appearance of the fabric. Unlike the state of art instrument which depends on the amount of diffracted light to evaluate the hairiness index, the developed instrument gives the count of the hairs at 3mm and 6mm from the yarn core at both the halves. Apart from this, hairiness is quantified by the hair length index and hair area index through image processing which are estimated by evaluating the ratio of total length of yarn to the length of yarn core and/or taking the ratio of total area of yarn to the area of yarn core.

3 Materials and Methods

3.1 Materials

Cotton, jute and polyester-cotton blended yarns were prepared and used for testing. The mixing of fibres was done according to the commercial practice[21]. The particulars of yarns are shown in Table 1.

Table 1 — Particulars of tested yarns

Yarn	Linear density, tex	Mixing
Cotton	25	F_{414}=50%, S_6=50%
	60	F_{414}=50%, S_6=50%
	120	F_{414}=25%, Desi= 50%, Soft waste=25%
	200	F_{414}=25%, Desi= 50%, Soft waste=25%
Polyester/ cotton blend	20	38mm 1.5 D Polyester=52%, F_{414}=25%
Jute	140	TD_3 Jute=100%
	235	TD_4 Jute= 50%, TD_5 Jute= 40%, Jute soft waste= 10%

3.2 Methods

3.2.1 Hardware of Developed Measurement System

The system developed for yarn characterization (Fig. 1) consists of cone stand, yarn guides, tension control device, motor with gear box for driving yarn delivery roller, pair of delivery rollers one of which is positively driven and the other rotates with friction of the previous one, display and control unit. A universal serial bus (USB) web camera accompanied with six LEDs, three in each half of the lens is used for illumination of the yarn. Similarly, photo transistor assembly estimates the diameter variation along with number of hairs. Light emitting diodes with convex lens are used for illuminating the yarn in case of photo sensing module. Both the sensing modules are placed in closed box whose inner sides are made black for reducing the interference and reflection of the light.

With the start of motor, yarn passes through yarn guides, disk tensioner and subsequently in front of the camera and photo transistors, which are used for
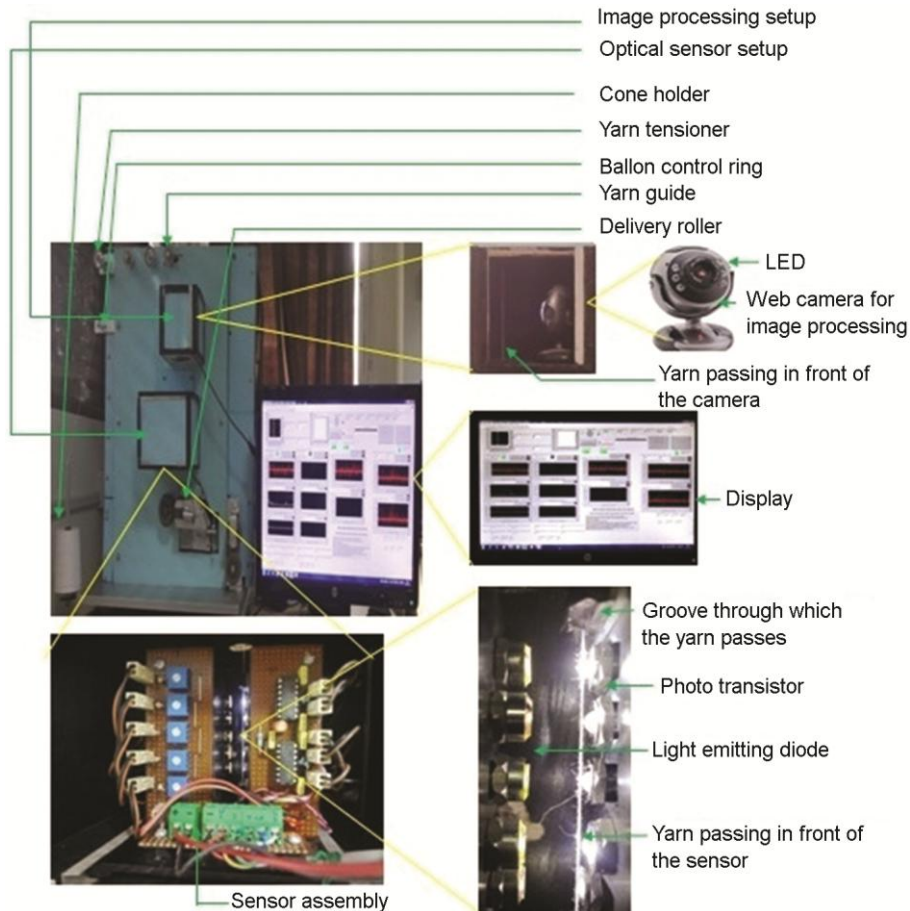

Fig. 1 — Newly developed System

detecting the change in yarn diameter. The output signal from optical sensor is fed to the Compact RIO for further processing. The image is processed in the computer with LabVIEW software. The monitor of the PC is used for displaying the results. Finally, a printer can be attached to get a report on paper. The speed of the motor can be varied from 5 rpm to 75 rpm, where 5 rpm drives 1 m of yarn in 1 min.

3.2.2 Processing of Yarn
Cotton Yarn

The fibres were mixed in required weight proportion with 10% water and then processed in blow room, carding, drawing, speed frame, ring frame and winding in a standard system with standard parameters[22].

Polyester/ cotton Blended Yarn

Polyester and cotton yarns were processed in cotton spinning system separately and then blended in first draw frame. It follows the standard procedure and parameters to make the yarn[23]

Jute Yarn

Jute reeds were treated with batching oil and water emulsion and processed through softener, carding, drawing, spinning and winding in jute spinning system using standard procedure and parameters[24].

3.2.3 Determination of Diameter
Measurement by Projection Microscope

Yarns were placed without tension as object in a projection microscope with goniometric eye piece and diameter was measured after 50 times magnification from the scale of eye piece. Average of such 50 readings was considered and actual diameter has been measured dividing by magnification.

Measurement by Image Processing

The diameter detection algorithm was executed with different threshold logic for extracting the core of the yarn. The captured image was made horizontal by 90^0. The luminance plane was extracted from the original image, resulting in the greyscale image followed by proper thresholding. Core of the image was extracted using the Robert filter. Particle filtering was done around the perimeter of the image for eliminating the grains due the fluctuation of the illumination. The yarn core extracted was divided into 20 equal sections and the edge difference of upper and lower edge of each section was measured giving diameter in pixels. The conversion of pixels to millimetre was done by calibrating the captured image

with that of the image of a standard wire of known diameter. Ten such snaps were taken to calculate 10 diameter values, average of which (D_{avi}) generates the central line in the diameter graph. It glows the record LED simultaneously indicating the instantaneous diameter measurement formally[Fig. 2(a)].

Measurement by Optical Sensor

The difference in voltage from the sensor without the yarn and with yarn has direct correlation with true diameter of yarn. The system keeps track of the diameter values for first 10 s and calculates average diameter (D_{avs}) of the yarn. The tracking time of the diameter can be changed to 20 s for improving accuracy. After 10 s the record LED for the sensor subsection glows and the instantaneous diameter was plotted over the average diameter as shown in Fig. 2(b).

3.2.4 Determination of the Yarn Imperfections
Measurement by Capacitive Method

Uster tester 3 is universally accepted as the instrument to measure yarn irregularity and imperfections. Selected yarns were also tested in this tester to compare the other systems with 50 m/min speed for 5 min following standard procedure[20].

Measurement by Image Processing

The processed image of the yarn was divided into 20 sections, the snap of 2 cm was divided into 1 mm and then the distance between the edges (D_{xi}) was calculated to determine the diameter. If four consecutive section of D_{xi} are between 1.5 and 2 times the average diameter D_{avi}, it is treated as thick place. Similarly, if the consecutive four D_{xi} values are less than half of D_{avi}, it is treated as thin place. Neps are considered for places with increase of the diameter more than 200% and existing for even 2 consecutive D_{xi} value.

Measurement by Optical Sensing

The effective cross sectional area of phototransistor has 1mm diameter. Therefore four consecutive values
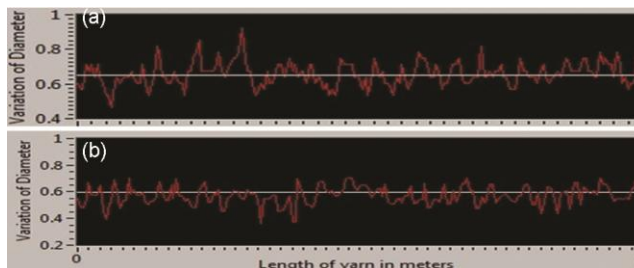

Fig. 2 — Diameter Variation by (a) image processing and (b) by optical sensor

from sensor D_{xs} were compared with 1.5 and 2 times the average diameter D_{avs} and it was treated as thick place. Similarly, if the consecutive four D_{xs} value is less than half of D_{avs}, it is treated as thin place. Neps are considered as those places with increase of the diameter more than 200% and existing for even 2 consecutive D_{xs} value.

3.2.5 Determination of Yarn Hairiness
Measurement by Image Processing(IP)
(i) Number of Hairs

For evaluating the number of hairs of the yarn, the edges of the hairs were counted at a distance of 3mm and 6mm (green marking) from the yarn core shown in (Fig. 3). For quantification the hairiness at each half, the hairs were counted at the specified distance.

(ii) Hairiness Indices

Hairiness was also evaluated by hair area and hair length indices. The grey scale image was inversed by look up table and then equalized. The image was then thresholded for the dark objects. The thresholded image was applied with the open object morphological operation followed by the dilation operation which results in the isolation of core of the yarn. The captured image was convoluted and thresholded for the proper visibility of the hairs. The image was then subtracted from the core of the yarn and advanced morphology function was applied. The extracted fibres were then segmented in to particles and the length and area of each particle was calculated.
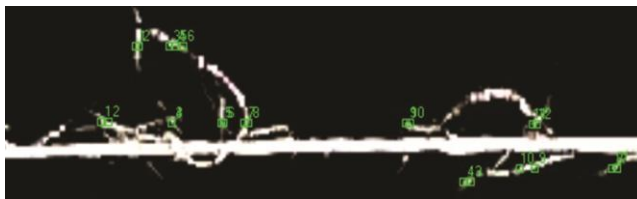

Fig. 3 — Numbers of hairs in both halves

Yarn is assumed as a rectangular object and with the known average diameter and the snap length, and the area of the yarn was calculated. The ratio of total area of the hairs and total area of the yarn core results in the yarn hair area index. Similarly total length of the hairs divided by the total length of the core gives the yarn hair length index.

Measurement by Optical Sensor

The sensors for measuring the number of yarn hairs were placed in both the halves from the yarn core at specific distances of 3 and 6mm. The difference from the base value of the sensor gives the presence of the hairs and the counter counts the hairs and gives the total number of hairs in a single run.

4 Results and Discussion

Three types of yarn, namely cotton, polyester–cotton blend and jute yarns with different linear density have been produced (Table 2). Same portion of all these yarns is tested in the developed set up (using image processing and optical sensing) in single run. To judge the accuracy of the instrument, same part of yarns is again tested manually by using projection microscope. Keeping microscopic study as the standard, on comparing image processing and optical sensing results it is found that in most of the cases t-values are well below 1.96, i.e. t_α at 5% level, resulting in insignificant difference between the two means. Only in coarse cotton (200 tex) and jute yarns (235 tex), real difference exists between optical sensing and microscopic means, possibly due to wide variation in the yarn and lower sensitivity for very coarse yarn in developed system. In optical sensing system it is observed that the coarse yarns sometime go out of the range of sensor. It has been optimised that 0.65 mm is the threshold diameter, below which the results are comparative with IP and microscope.

Table 2 — Average diameter values by image processing and optical sensing

Yarn	Linear density tex	Diameter, mm			t- value	
		Image processing (IP)	Optical sensing (OS)	Projectina (M)	Between IP & M	Between OS & M
Cotton	25	0.44	0.42	0.42	0.36	0
	60	0.55	0.51	0.53	0.54	0.76
	120	0.60	0.58	0.60	0	0.69
	200	0.81	0.86	0.79	1.45	2.26
Polyester/ cotton (52/48)	20	0.39	0.40	0.42	1.05	0.57
Jute	140	0. 56	0.55	0.56	0	0.49
	235	0.94	0.90	0.95	1.69	2.13

Table 3 shows the short term CV% of cotton, polyester-cotton blend and jute yarns with image processing, optical sensing and Uster tester. It is observed that Uster tester values mostly corroborates with image processing. Values from optical sensors are always higher because of effect of hairiness. Statistical t- test shows that coarse yarns are producing erratic results. Introduction of polyester with cotton shows comparable values in all the systems due to very low moisture regain, longer and finer fibre and low hairiness. Statistical t-values which are lower than 1.96 shows no statistical difference in two CVs, whereas higher values depict the existence of real difference between two CVs. Cotton-polyester yarn shows very good correlation (above 90%) in almost all the measured parameters between IP & OS system possibly due to presence of 52% polyester fibre which is having almost no variation in fibre length and fineness. This is the reason why lower imperfections are generated (Table 4).

Table 4 shows the number of thick (+50%), thin (-50%) and neps (200%) of same part of different yarns measured in two principles and expressed in terms of per km reading. The results are further compared with standard Uster tester. The results from the developed instruments are similar to the results of the Uster tester. Table 4 shows the imperfection data of different yarns with image processing & optical sensing considering 1 mm and 8 mm cut length.

In both the systems, hairs are measured along extreme top and bottom lines along the yarn axis. Number of hairs per meter of different yarns in two sensing systems are shown in Table 5. In all cases, optical sensor shows higher values than image processing. This is due to higher resolution of OS. It actually covers total tested yarn length. But in image processing snaps are taken in 1 mm gap, though it can be changed by the software. Then high speed and more powerful processor is required to process huge volume of data. Therefore, number of data in case of

Table 3 — Comparison of irregularity parameters of the developed instrument and Uster tester

Yarn	Linear density tex	CV%			t- value	
		Image processing (IP)	Optical sensor (OS)	Uster Tester (UT)	Between IP & UT	Between UT & OS
Cotton	60	13.99	18.9	13.44	1.34	3.62
	200	21.76	27.87	19.89	2.02	4.29
Polyester/ cotton (52/48)	20	10.62	10.89	10.72	0.72	0.89
Jute	140	31.29	36.57	31.68	4.75	1.12

Table 4 — Yarn Imperfections from different sensing methods

Type of yarn	Linear density tex	Imperfections/km by image processing			Imperfections/km by optical sensing		
		Thick places	Thin places	Neps	Thick places	Thin places	Neps
Cut length 1 mm							
Cotton	60	22	12	33	20	13	30
	200	15	24	13	13	20	15
Polyester/ cotton (52/48)	20	10	14	13	12	15	10
Jute	140	34	28	0	12	15	0
Cut length 8 mm							
Cotton	60	7	0	10	5	0	12
	200	82	1	46	80	0	40
Polyester/ cotton (52/48)	20	4	0	13	3	1	11
Jute	140	14	11	0	17	10	5

Table 5 — Numbers of hairs by different sensing methods

Yarn	Linear density tex	Hairs/m by image processing				Hairs/m by optical sensor				Zweigle tester	
		3mm Right	6mm Right	3mm Left	6mm Left	3mm Right	6mm Right	3mm Left	6mm Left	3mm	6 Mm
Cotton	60	82	19	81	17	101	21	98	18	96	18
	200	112	24	108	25	134	22	139	25	130	24
P/C[*] (52/48)	20	56	16	58	15	78	26	75	25	73	28
Jute	140	87	69	90	66	103	75	98	76	102	72

[*]Polyester/cotton.

OS is higher than in case of IP for the same length of yarn tested. However, data from these two system show that jute yarns contain long hairs in highest numbers among the different types of yarn tested followed by cotton yarn. Polyester cotton shows the lowest long hair. These hairs are mostly detrimental for further processing and also in appearance. For jute yarn, around 75% of the hairs are long i.e. above 6 mm height due to wide variation in length and fineness, whereas only around 25% hairs are long in coarse cotton. The more the short hairs better will be feel and comfort.

Figure 4 shows the hair area index and hair length index of jute yarn. The same trend is observed in both the indices.

The software is also developed in such a way that both sensors initially go on measuring diameter variation independently for 10 s. It then plots the average diameter from the 11th second considering instantaneous diameters. It is obvious that image processing is a comparatively slower process and depends on speed and resolution of camera as well as processor used. Higher speed demands higher cost of instrument. In the present set up, the yarn speed cannot be increased more than 25 m/min, as captured image at higher speed gets blurred and is impossible to evaluate effectively. On the other hand, optical sensor can evaluate yarn parameters easily at 75 m/min in present set up.

The same yarn has been tested 50 times in both the measuring systems in same speed and length. It is found that the diameter, imperfections and hairiness values show insignificant difference in 1% confidence level for IP whereas it is insignificant within 5% confidence level for OS. Therefore, the
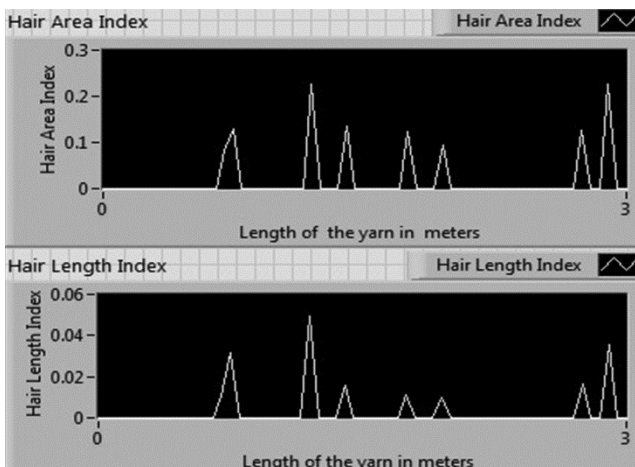

Fig. 4 — Hairiness Indices for Jute yarn of 235 tex

data from IP and OS are reliable and repetitive in nature.

5 Conclusion

5.1 Image processing can be a good alternative of universally accepted capacitive measurement with availability of accurate, versatile and detailed information at slower speed. The yarn speed depends on the quality (resolution and speed) of camera.

5.2 Optical sensing process is much faster but shows slightly higher hairiness values than image processing.

5.3 Results of image processing and optical sensing are reliable and repetitive.

5.4 Dedicated software has been developed which is inbuilt within the system and measures the attributes from both the sensors efficiently with options of selecting any cut length.

5.5 Uster tester results mostly corroborate with image processing. Values from optical sensor are always higher.

5.6 Quality of illumination is an important factor for accuracy in measurement by Image processing, as well as optical sensing. It should have constant and uniform strength. It works better in covered dust free sensing zone.

5.7 Yarns with the diameter value up to 0.65 mm are suggested to be evaluated by optical sensor in the developed instrument as above this threshold, the measurement with optical sensing is not as reliable as its counterpart. In such cases, testing by image processing is more reliable.

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