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# A VISION BASED YARN SCANNING SYSTEM

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## Abstract

A new charge coupled device (CCD) linescan camera based yarn data acquisition system for textile yarn characterisation is reported. An interface scheme for the Fairchild CAM 1350 linescan camera to a Motorola M68000 single-board computer, with a parallel data link to an IBM-PC, is described. Yarn analysis software is developed to allow investigation of different yarn characteristics. The results demonstrate applicability as a fast laboratory investigative tool and show further promise for the technique to be extended to full yarn processing speeds allowing on-line monitoring and control of the yarn production processes.

## 1. INTRODUCTION

Textile yarns may possess non-uniformity in a variety of properties, such as twist, bulk, strength, thickness or fineness along their lengths. Such variations are inevitable because they arise from the fundamental nature and properties of the textile fibres, both natural and man-made, and their arrangements to form yarns. The term "yarn evenness" is usually used to describe variations in fineness [1]. This may be measured in terms of variations in mass per unit length. However, yarns produced from different fibres by different techniques and processes have very different characteristics that require quantifying. Whilst a straightforward evenness test may be adequate for one type of yarn, we may require different tests to characterise different types of yarns, such as hairiness of spun staple fibre yarns, loop size and density of air-jet textured yarns, entanglement frequency and regularity of intermingled textured yarns.

Hairiness of a spun staple fibre yarn occurs because some fibres protrude from the yarn body; other fibres arch into loops, emerging from the yarn core. Fibre hairs surrounding a textile yarn may adversely affect the operations which follow spinning, such as weaving and knitting, and may influence the characteristics of the finished product [2, 3]. Hence, measurement of yarn hairiness has become an essential and routine test in the textile industry. Continuous filament yarns may be textured to gain physical appearance and surface properties similar to those of spun yarns. Such an example is the air-jet textured yarn which has a spun-like structure with a compact core and surface loops occurring randomly along its length [4]. These loops are very much like the fibres protruding from the surface of a spun yarn but with closed loops instead of free fibre ends. Therefore, measurement of loop size and density, similar to the yarn hairiness measurements, is very crucial to the quality assessment of the air-jet textured yarns.

Synthetic continuous filament yarns are usually textured by conventional texturing techniques, such as false-twist texturing, prior to their successive usage in further processes [4]. Unlike spun yarns, in which the inter-fibre friction, attributed to the twist, provides the main cohesive force that holds the staple fibres together to form the yarn, false-twist textured yarns lack such inter-filament cohesion. One of the modern techniques of imparting such cohesion is the air-intermingling of false-twist textured yarns which imparts regular but intermittently entangled nodes to the open structure of the textured yarn which are commonly known in industry as "nips" [5]. The frequency and regularity of the nips are important criteria in the assessment of the performance of mingling nozzles and the quality of the intermingled yarns.

## 2. YARN CHARACTERISATION

Yarn evenness is measured by various methods [1]. The most commonly used methods are the capacitive methods which detect the variations in mass per unit length placed in a field of an electrode. Optical methods use the principle of a silhouette to obtain a reading, usually from the shadow of the yarn, the area of which is taken to be proportional to the mass of the yarn specimen.

Yarn hairiness is a rather complex feature to analyse, which generally cannot be completely defined by a single indicator. This is usually measured in terms of the number of protruding hairs per unit length and the length of hairs. Numerous measurement techniques have been developed [2, 3]. These are mainly based on the use of photographic, microscopic, photoelectric and optical techniques. Some use electrostatics to make hairs stand upright and then measure the hairiness. Modern hairiness measurement instruments use optical techniques such as detecting the scattering light from a laser beam by fibres protruding from the main body of the yarn and detecting protruding fibres by means of a series of photocells [3, 6].

Hairiness instruments usually measure two parameters: the number of hairs per unit length and the hair length, which together provide a measure of overall yarn hairiness needed by industry. All current hairiness measurement instruments are of an off-line laboratory type which operate at relatively low yarn transport speeds. None of the instruments is based on digital data acquisition technique.

There has been a number of efforts to quantify the loop size and density of the air-jet textured yarns. A review of such techniques shows that the earlier techniques consisted of tedious and subjective methods of analysing yarns under microscopes or micro-projectors, and by use of micro-densimeters or photo diodes [7]. Such methods were in the main tedious and inaccurate, and failed to provide objective and reliable quantitative characterisation of air-jet textured yarns. Most recent and advanced techniques were based on the use of scanning the yarn in the direction perpendicular to its axis by using a CCD (charge coupled device) line scanner. One such experimental system was developed at Loughborough University of Technology which demonstrated the potential of the CCD based image analysis systems [7].

Various instruments are available in industry for the measurement of nip frequency and regularity and distance between nips. These instruments are usually based on tactile sensors, infrared sensors, or a weight type needle sticking method. These are mainly intended for laboratory use. One of the current instruments can measure nip frequency at production speeds. In the late 1980s, a high speed, high accuracy CCD based instrument made a brief appearance, which was claimed to perform as nip frequency counter as well as an evenness tester, hairiness tester and linear density monitor, among many other functions.

There is still a vacuum in the high speed end of the yarn characterisation instruments and a need for a non-contact vision based system which is capable of operating at high yarn production speeds, as well as functioning as a sophisticated laboratory test instrument.

### 3. NEW YARN SCANNING SYSTEM

A new instrument for non-contact yarn canning, data acquisition and analysis based on a CCD linescan camera sensor is described. Detailed image acquisition and off-line complex data analysis, providing comprehensive information to the user, is one mode of operation. A high-speed reduced resolution image acquisition system, requiring less data processing to provide on-line assessment of yarn quality, is proposed as the second mode of operation.

#### 3.1. System requirements

The yarn scanning system described here has been developed as a self-contained off-line unit which can be used to acquire data from yarn transported in a separate mechanical system at speeds of 0.1 m/s. The vision system consists of the following elements.

- CCD linescan camera.
- Yarn illumination.
- Image acquisition and storage.
- Image processing, analysis and display on PC.

Figure 1 shows a block diagram indicating the elements required to form the vision system.

#### 3.2. Optical aspects

Previous work in the field [8, 9] indicated that depth of field has to be adequate for the two dimensional nature of the yarn. Also, two orthogonal views of the yarn in the same cross sectional plane would be necessary to characterise the yarn adequately. The camera used in this project is a Fairchild CAM1350 linescan camera with 1024 pixel elements. Each pixel element in the camera is  $13 \mu\text{m} \times 13 \mu\text{m}$  with a pixel pitch of  $13 \mu\text{m}$  [10]. The camera is fitted with a 50 mm focal length lens. There are a number of conflicting parameters which affect the quality of the image captured.

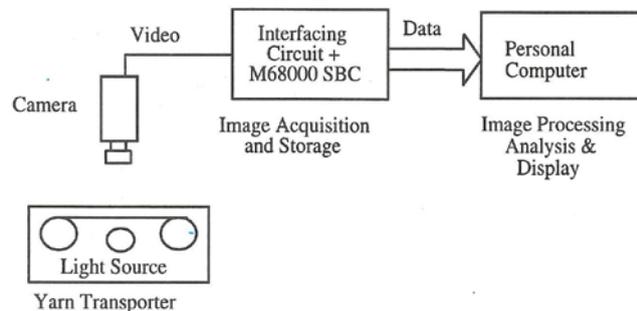


Fig. 1. Elements of the vision system.

These parameters are:

- Magnification.
- Depth of field.
- Aperture.
- Light intensity.

Depth of field of the yarn object is determined by

$$D = 2fdc(m + 1) / (m^2d^2 - c^2) \quad (1)$$

where

$$D = \text{depth of field}$$

$f$  = focal length of lens (50 mm)  
 $d$  = aperture  
 $c$  = limit of resolution (13  $\mu\text{m}$ )  
 $m$  = magnification.

An evaluation of the effect of magnification and aperture on the depth of field has been carried out [9]. The results show that there is a tradeoff between magnification, aperture and depth of field. The higher the magnification, the smaller is the depth of field. The depth of field could be increased by reducing the aperture. However, there is a limit to how small the aperture can be because the CCD array of the camera needs a minimum amount of light for pixel registration. Whilst the light intensity can be increased by additional light sources and intensifying optics, the intensity cannot be increased indefinitely. Therefore, a compromise between these parameters has to be reached and at the same time satisfy the system requirement field of view. The yarn scanning instrument is based on the following parameter values for the linescan camera: magnification  $\times 1$ ; f-number ( $f/d$ ) 7.8; depth of field 0.41 mm.

Back lighting is the chosen method of illumination in order to reduce the image processing task. Illumination in this case is provided by a 9V tungsten lamp from a D.C. supply. This method will reveal in silhouette the fine detail of the yarn extremities. Higher yarn processing speeds require faster scan rates which will present increased demands on the method of illumination. A mirror inclined at  $45^\circ$  to the viewing plane can provide an additional orthogonal view of the yarn image, as shown in Fig. 2. A field of view of 13 mm is provided with this experimental set up which is adequate for scanning both views of the yarn on the same CCD array.

### **3.3. Microprocessor system**

The M68000 single-board computer system (SBC) used as the data acquisition computer has the following features [11].

- Full 16-bit microprocessor.
- Direct access to all non-multiplexed asynchronous address and data buses.
- 64K Bytes of EPROM expandable on board up to 512K Bytes.
- 64K Bytes of RAM expandable on board up to 1M Bytes.
- On board Programmable Interface/Timer support (M68230 PIT).
- Unused memory space for external peripheral support.

### **3.4. Image acquisition interfacing scheme**

The video signal from the camera needs to be digitised before it can be used for image processing and analysis. For the yarn image which requires only the outline information, binary representation is the best choice. It requires less memory and the image processing time is also much faster than grey level representation. The main objective of the interfacing circuit is to convert the video signal from the camera to a binary representation and combine these individual bits into a word of 16 bits so that it can be easily read and manipulated by the M68000 SBC. Figure 3 shows a block diagram of the image acquisition interfacing circuit, with external connections to the camera and M68000 SBC system.

#### *3.4.1. Address decoding circuit.*

Address decoding is performed by using programmable logic devices (GAL16V8) providing a compact and flexible solution. The GAL16V8 generates chip select signals for the digital to analogue converter (D/A) and the 16-bit latch. It is also used to generate the required DTACK signal for asynchronous data bus operation.

Partial decoding is used here for accessing the D/A converter and 16-bit latch. The D/A converter is an 8-bit device and therefore has to be addressed through an odd address. The 16-bit latch is accessed through even addresses in the designated memory block.

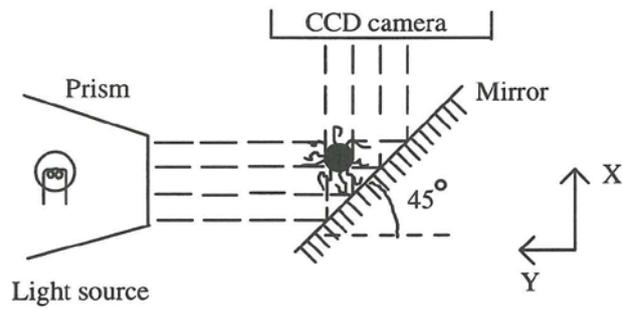


Fig. 2. Arrangement for two orthogonal views of yarn image.

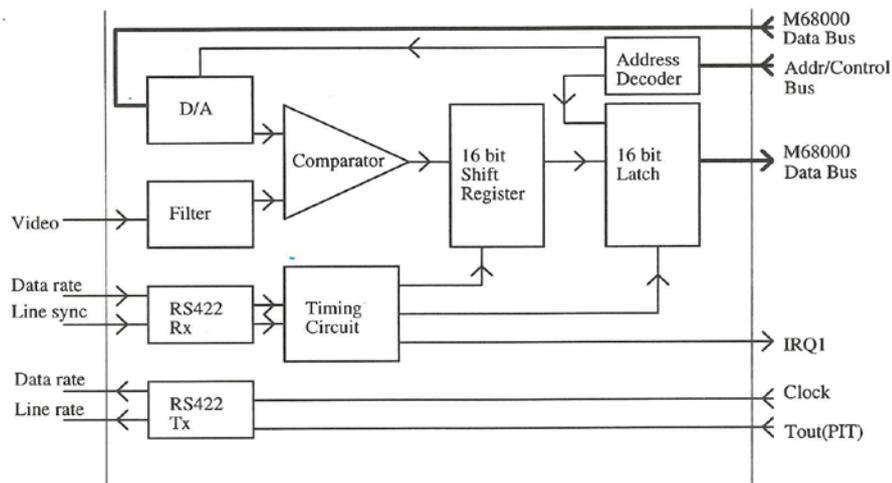


Fig. 3. Block diagram of image acquisition interfacing circuit.

### 3.4.2. Signal levels.

All the control and timing signals (except the video) coming from and to the camera are in differential signal (RS422) for long distance transmission. Therefore RS422 transmitter and receiver circuits are used for the required signal conditioning. The RS422 transmitter and receiver used here are 75174 and 75175 respectively. The video signal is D.C. restored and saturates at 1V.

### 3.4.3. Video signal pre-filtering.

The video signal coming from the camera has some inherent noise in it. It also picks up some interference along its transmission path. Since the quality of the video signal determines the quality of the image captured, pre-filtering of the video signal is essential to eliminate the high frequency noise. The filter used here is a first order RC filter to give a break frequency of 700 kHz. The values of R and C have to be chosen to ensure that the amplitude of the video signal is significantly reduced and its frequency components due to yarn characteristic (i.e. nip or hairiness) are not filtered out. This involved many iterative steps to get the final values.

### 3.4.4. Binary imaging.

A ZN428 D/A converter and an NE527 high-speed analogue comparator are used to establish a binary image of the yarn. The D/A converter generates an analogue threshold voltage which is compared with the video signal from the camera, after filtering. The threshold value for

comparison is software programmable. Since the video signal never exceeds 1 V the thresholding voltage does not need to be greater than 1V and a unipolar voltage is sufficient. Therefore, the D/A is configured for unipolar operation, with an output voltage range from 0 to 2.5V. This configuration is the simplest and does not need an additional operational amplifier. The output of the analogue comparator is a TTL signal that is dependent on the difference between the thresholding and video signals.

#### 3.4.5. Bits to word conversion circuit.

The binary output from the analogue comparator needs to be combined into a 16-bit word before it can be read by the M68000 SBC. This conversion can be achieved by using a 16-bit shift register and a 16-bit latch. Overall bit synchronisation is required for proper operation of the circuit. This synchronisation is provided by the timing circuit.

#### 3.4.6. Timing circuit.

The timing circuit is the heart of the image acquisition interface. The operation of the timing circuit is best discussed with the help of the timing diagram shown in Fig. 4. The *line rate* signal is generated by the M68000 to start a new scan line. It is generated by the M68230 PIT on the SBC. Its frequency determines the linescan rate of the vision system. This signal is sent directly to the camera, after signal conditioning. The camera also needs a *data rate* signal for clocking the pixels. This signal is obtained from the SBC system clock (8 MHz) and divided by 8 (using a 4-bit counter - 74LS393), to give a data rate of 1 MHz. The camera returns *line sync*, *data rate* and *video* signals. The *line sync* and *data rate* signals from the camera are used by the timing circuit to generate the signals to synchronise the operation of the interfacing circuit. An inverted version of the *data rate* from the camera is used to clock the 16-bit shift register. This is to ensure that the pixel information is read into the shift register at the mid-point of the pixel pulse. The *line rate* from the SBC is used together with the inverted *line sync* pulse from the camera to generate a *reset* pulse at the start of each new scan line. This *reset* signal is used to reset the modulus 16 counter at the start of each scan line to detect the occurrence of every 16 clock cycles of the *data rate* from the camera, which signals that the output of the shift register is valid. The 74LS123 multivibrator is used to generate pulses of suitable duration (1.5  $\mu$ s) for the *data available* pulse and *line sync* pulse to be used by the SBC. The *line sync* pulse is connected to the IRQ1 of the M68000 system, to indicate the start of a new scan line. To save software processing time, an interrupt approach has been used to detect the start of a new scan line. The *data available* pulse is used to latch the 16-bit data at the output of the shift register into the 16-bit latch. This is used by the image acquisition software to detect whether a valid word of data has been latched. The data available synchronisation is done by generating the DTACK signal only when the data has been latched into the 16-bit latch.

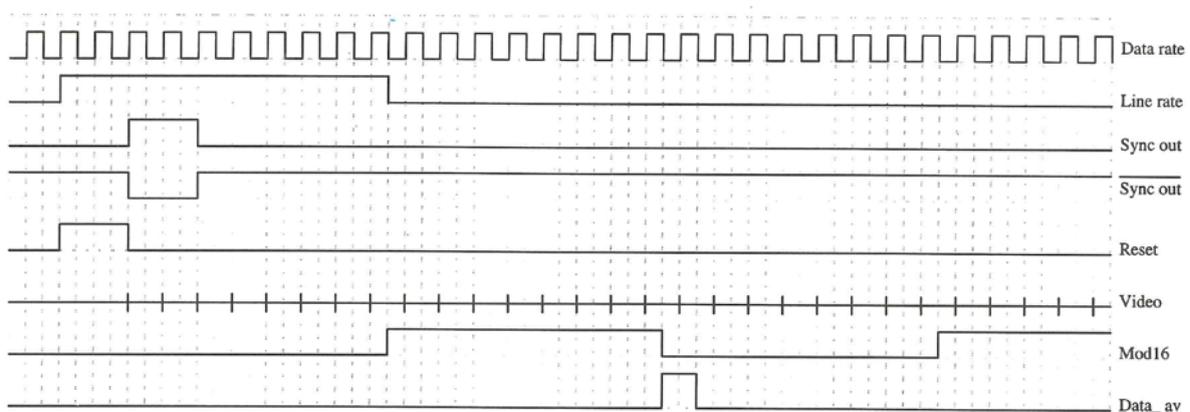


Fig. 4. Timing diagram for the image acquisition circuit.

### 3.4.7. Image acquisition.

The timer system in the M68230 is initialised for periodic square wave generation. This square wave is sent to the camera as the *line rate* signal for the start of each linescan at the positive rising edge. Once a start signal is detected by the SBC (in this case a push-button on the user interface), an interrupt service routine is used to capture the image data. Inside the interrupt service routine, the M68000 SBC is polled for the *data available* pulse before reading the word data from the 16-bit latch. This process will repeat for 64 times to capture 1024 bits of binary data. In actual fact, there are 1046 (22+1024) pixels for one linescan. The first 22 pixels are generated by the camera drive circuit preceding the first active pixel and are ignored.

### 3.5. Image data communication

The digitised image data needs to be transferred to PC for image processing, analysis and display. For large volumes of yarn image data, parallel transfer is the preferred method. For an image of 256 x 256, and using binary representation, the amount of memory needed to store the image is 8K bytes, with parallel transfer to the PC accomplished within 1 s. The M68000 SBC uses the M60230 PIT and the PC uses the 8255 PIA to implement the parallel data transfer. The PC and M68000 SBC operate a software handshaking protocol to handle data transfer effectively.

### 3.6. Image display

Yarn image display is an important aspect of the vision system for yarn characterisation. It serves the purpose of verifying that the image data captured is satisfactory and also provides the user with a "magnified" view of the image on the monitor. An image contains a large amount of pixel data, and a 256 x 256 image has 65,536 pixels to manipulate. Data is displayed by direct access to the PC's video controller registers and memory, providing excellent display response.

### 3.7. User interface

A menu driven user interface is provided on the PC. This menu provides the user with a list of operations which can be performed by the vision system developed. A sample of the menu output is shown, which is self-explanatory.

#### Menu Selection

- (A) cAlibration
- (C) Capture and display image
- (S) Save image to disk
- (G) Get image from disk
- (D) Display image
- (P) Print data buffer
- (F) FFT (one dimension)
- (H) High Pass Filtering
- (L) Low Pass Filtering
- (T) Longitudinal-Transverse distribution analysis
- (Y) sYstem Information
- (M) Menu
- (Q) Quit

### 3.8. Digital image processing

Image processing is used to enhance the quality of the image for subsequent yarn analysis. Two approaches have been investigated to perform image processing: (i) spatial domain methods and (ii) frequency domain methods. Image processing tools have been developed in "C" for spatial filtering using convolution masking techniques. Low pass spacial filters that attenuate the high frequency components while leaving the low frequency components untouched have been applied, thus producing a smoothing of the fine detail of the image. High pass filters

which attenuate the low frequency components, responsible for the slowly varying characteristic of an image, have also been used, thus sharpening up the image, highlighting edges and other details. Fourier transforms have been implemented in software to examine the frequency content of the yarn image.

### 3.9. Overall system configuration

The following system configuration is used in the vision system of yarn quality assessment.

- Fairchild CAM1350 linescan camera.
- Camera magnification 1:1.
- Binary image data representation with back lighting.
- M68000 Data Acquisition Computer.
- Parallel communication for data transfer to PC 386.
- Image displayed by direct access to video controller's registers and memories.
- Software image processing tools.
- Yarn image characterisation.

## 4. YARN IMAGE ANALYSIS

Yarn exhibits a large variety of properties which require analysis. Since the yarn image data is in a digital form a range of image processing possibilities exist. The data acquired from the M68000 single-board computer can be presented as transverse and longitudinal distributions as shown in Fig. 5. The transverse distribution is formed by accumulating the number of high pixels for each scan line. The longitudinal distribution is created by accumulating the number of high pixels for each CCD sensor, for the whole yarn sample length. These distributions can be analysed in the spatial or frequency domains for the purpose of characterising the yarn.

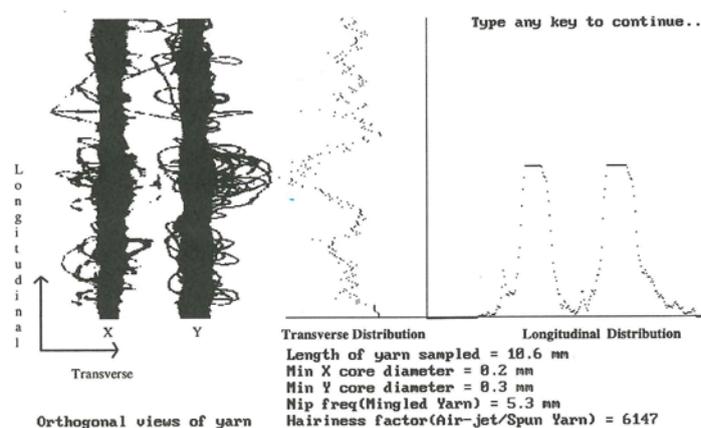


Fig. 5. Yarn image analysis using spatial distribution.

### 4.1. Yarn characterisation

Three types of yarns have been analysed to show the potential of the new system. These are: false-twist textured mingled yarn, air-jet textured yarn and natural spun yarn. False-twist textured mingled yarn can be characterised by nip frequency. Air-jet textured yarn and natural spun yarn can be characterised by hairiness.

#### 4.1.1. Core thickness.

There are many ways to define the diameter of a yarn. Here, the average core diameter of each linescan has been used to define the yarn core diameter. This parameter can be obtained from the

longitudinal distribution. Since two orthogonal views are available, both  $X$  and  $Y$  core diameters can be computed. This provides the possibility of measuring yarn evenness.

#### 4.1.2. Nip frequency measurement.

Individual nip pitch can be established from the transverse distribution of the data in both spatial and frequency domains, providing a measure of nip frequency and nip pitch variation. Previous research [12] indicates that a yarn image can be modelled in three parts: the straight yarn without any hair structure, the hair structures itself, and the effects due to diffusion of the optical light. These parts are claimed to be easily distinguishable in the frequency domain but not the spatial domain. Hence it is clear that the FFT is an area worth investigation.

#### 4.1.3. Hairiness.

There is no standard hairiness definition and its measurement is method dependent. The method presented here uses the longitudinal distribution data providing a normalised index of yarn hairiness, defined as the ratio of the total area under the distribution (i.e. the contribution of both yarn core and protruding hairs) to the area of the yarn core:

$$\text{Hairiness Index} = \text{total area} / \text{area of yarn core.}$$

The width of yarn core is defined as the average number of solid, unbroken pixels for each linescan. Other pixels lying outside the core can be set by protruding yarn hairs which contribute towards the calculation of the total area. Obviously a higher index indicates greater hairiness. From the variance of the transverse distribution of the data, further information on the hair length can also be obtained.

## 4.2. Experimental results

A number of representative yarn images from each of the three types of yarns under investigation have been analysed using the spatial distribution and FFT methods. A typical output from the analysis package is shown in Fig. 5. Examples of yarn images obtained with the new system are shown in Fig. 6.

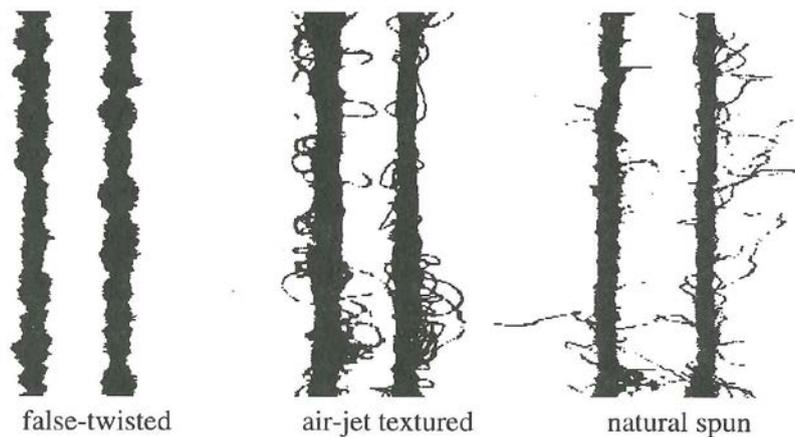


Fig. 6. Examples of yarn images obtained.

Table 1 presents results obtained from eight different samples each of air-jet textured and natural spun yarns. Average hairiness indices together with core diameters in  $X$  and  $Y$  directions are shown. These results have been obtained at a yarn speed of 80 mm/ and a linescan rate of 1 kHz. The hairiness index of air-jet textured yarn is found to be less than that of natural spun yarn. Visual inspection of the two samples shows this to be the case. The  $X$  and  $Y$  core diameters obtained from two orthogonal views of the yarn, presented in Table 1, show the potential for obtaining a measure of yarn roundness as well as yarn evenness.

Using a one-dimensional Fourier transform of the transverse distribution an average measure of the nip frequency (hence pitch) of false-twist textured mingled yarn was obtained and compared well with visual inspection results.

Table 1. Spatial distribution analysis for air-jet textured and natural spun yarns

Yarn type	Measure	Hairiness Index	$\bar{X}$ diameter (mm)	$\bar{X}$ diameter (mm)
Air-jet textured	Mean	1.139	0.263	0.234
Natural spun	Mean	1.196	0.215	0.230

### 4.3 Simulation of yarn production speeds

The ultimate aim is to use this system as a production monitoring and control device, possibly in a feedback control system. When the yarn is transported at high production speeds (for example a range of 5-10 m/s is typical of the air-jet texturing process) the distance that the yarn travels between each linescan of the yarn increases (for constant linescan rate). Obviously the visual image of the yarn obtained at high yarn transport speeds will not be a true likeness of the yarn structure. However, the data obtained will be statistically sensible and will lend itself to the calculation of the yarn Hairiness Index. In order to establish this, a further test was carried out to determine the influence of linescan rate relative to yarn throughput speed.

It was not possible to move the experimental rig to a production line to test the capability of the system at high production speeds. However, high production speeds were simulated by reducing the linescan rate in predetermined steps to 80 Hz. By doing so the distance travelled by the yarn between each scan was increased and hence representative production speeds were simulated. The results of yarn Hairiness Index measurements are shown in Table 2.

Table 2. Effect of sampling frequency for natural spun yarn at traverse speed of 80 mm/s

	Linescan frequency				
	1 kHz	800Hz	320Hz	160Hz	80Hz
Distance travelled by yarn between scans	80 $\mu$ m	100 $\mu$ m	250 $\mu$ m	500 $\mu$ m	1mm
Hairiness Index	1.081	1.073	1.028	1.026	1.015
Standard deviation	0.019	0.016	0.004	0.004	0.003

This shows that the Hairiness Index decreases with decreasing linescan rates (simulated increase in yarn speeds). Measurements at lower linescan rates have lower standard deviation indicating increased consistency between measurements.

This work reported indicates that the system developed is also capable of measuring yarn hairiness at production speeds.

## 5. CONCLUSIONS

A new yarn assessment concept using a machine vision system based on a low cost M68000 single-board computer, a Fairchild CCD linescan camera and personal computer (PC) has been developed. This comprises: image acquisition circuit to allow the video signal from the camera to be digitised using binary representation, data transfer hardware and software to upload compressed image data to the PC, image processing tools for yarn analysis in the spatial and frequency domains.

Three types of yarn have been analysed using the new system. These are intermingled false-twist textured yarn, air jet textured yarn and natural spun yarn. The determination of nip pitch (and hence frequency) using a method based on a one-dimensional Fourier transform of the transverse distribution of the yarn image gives promising results. A normalised Hairiness Index has been defined and the new yarn scanning system has been used to obtain representative hairiness indices of air-jet textured and natural spun yarns. Data produced in each case demonstrate the potential of the new system, which is faster, non-invasive and will eventually be suitable for on-line measurement, leading to adaptive control of the yarn production processes.

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