TITLE: Real Time Yarn Characterization and Data Compression Using Wavelets

CODE: I97-S1

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GOAL:

To design a holistic system for measurement, control, and quality maximization in textile fiber processing through on-line measurements (data fusion) and data analysis using “wavelet” theories and stochastic models. The system being developed extracts, retains, and synthesizes only the essential information required for characterizing the salient qualities of yarns and fabrics, without having to process and store vast amounts of data acquired on-line. This task will provide the textile industry with a meaningful and cost-effective quality monitoring and measurement system which presently does not exist.

ABSTRACT:

Much of our effort for the project was focused on developing an integrated, simultaneous yarn measurement system which combines optical and capacitor sensors. Using the system, we studied the relationship between the mass density and diameter measurements obtained from the two types of sensors. We also analyzed and compared density profiles obtained from several spun yarns. A scheme has been successfully developed, tested, and applied to extract, retain, and synthesize only the essential information required for characterizing the salient qualities of yarns and fabrics, without having to process and store vast amounts of data acquired on-line. More specifically, the system developed is capable of i) performing data reduction through wavelet analysis and stochastic parameter estimation, ii) localizing the quality features and their abrupt changes in time domain through signal processing, iii) generating a large amount of yarn profile data from the compressed wavelet-stochastic parameters, and iv) producing a large area of simulated fabric image for quality visualization. At this point, the hybrid system is capable of achieving 1 to 100,000 data reduction. In an actual application, 10 spindles were measured, 25,000 meters each, to provide the essential system parameters for data reduction, data expansion/regeneration and visualization of simulated fabric quality. This preliminary experiment suggests that the entire data from monitoring 200 spindles for 8 hours can be stored and retrieved effectively in time domain with little difficulty. The progress made thus far provides a real prospect of designing a futuristic wavelet-stochastic hybrid system for yarn and fabric quality monitoring, characterization, control and improvement.

RELEVANCE TO NTC GOALS:

To compete internationally, the U.S textile industry must capitalize on its strength: information and computer technologies, and a high-technology infrastructure. These strengths facilitate an environment for high quality and customer-driven QR networking. The project incorporates these
strength through the PI’s diverse backgrounds (Tex. Eng., Mech. Eng., Stat.) for educating students and transferring the technology to the industry.

**OBJECTIVES:**

1. To design and construct a new system for measurement, control, and quality maximization in spun yarn manufacturing by combining the diameter and mass density signals of yarns, which in turn would provide a superior prediction of the visual qualities of the resulting fabrics.
2. To develop data compression algorithms based on wavelet and stochastic analyses by which a large amount of data can be compressed and stored without a significant loss of the original information.
3. To develop a quality monitoring and control system by combining wavelet and stochastic models for maximizing data reduction rate.
4. To predict and visualize fabric qualities directly from yarn density profiles through the measurement and analysis systems developed.

**TECHNICAL APPROACH:**

**A. Development of a Signal Capturing and Processing System**

Variation in mass per unit length and diameter of yarns have long been the most important characteristic in textile processing and quality control. The existing commercial systems, such as Zweigle G-580® and Uster 3®, however, are inadequate for measuring the real features of yarns as they measure either the mass or diameter, but not both. Consequently, the signals obtained from these are markedly different from the visual qualities of the yarns and the resulting fabrics. In addition, the true and complete quality features of the yarns are not fully revealed by these conventional systems. For overcoming the limitation, we are developing a multi-sensor, simultaneous yarn measurement system by combining optical and capacitor sensors. In the new system, both the mass density and the diameter are measured and combined in such a way that the two quantities are matched in spatial domain and transformed into a new physical quantity we have yet to name. The new system consists of 1) optical and capacitor type sensors, 2) a tension control device, 3) a yarn guide for dampening tension variation, and 4) a signal processor. Figure 1 shows the photographs of two individual systems for measuring diameter and mass, respectively. The two systems will be integrated into one simultaneous yarn measurement system by mounting the sensors in a constant tension control device shown in Figure 1(b).

**B. Data Reduction Using Wavelet-Stochastic Hybrid method**

With faster sensors and modern data-acquisition systems, the data flow rate has increased exponentially over the last few years. For a yarn length of only 600m, the size of data file required has to be at least 1.2 MB. Yet, the presently available analytical methods either compress the data into a single CV% [1], or convert the entire data set into a spectrogram [2], deleting the important spatial information completely. In practice, because of the redundancy embedded in the 1.2MB signals, the entire data can be compressed to less than 5% of the original 1.2 Mb based on our initial efforts by applying the wavelet analysis alone. This can be shown in Figure 4 where the simulated fabric image from the compressed data is shown to be almost
identical to that of the original data. The key question for our project is how to best represent the totality of yarn characteristics with a minimal amount of data. This involves measuring one or more physical characteristics (mass density, diameter, hairiness) on-line, combining the information (data-fusion), analyzing the data (filtering, data compression), and presenting them in a meaningful form for decision support and feedback control. It has been found that the wavelet transform offers many advantages over other methods in performing data compression, space-frequency analysis, and texture characterization [3]. Previous studies in other fields [4, 5] suggest, and our study confirms, that the wavelet-based multi-resolution analysis can be an excellent tool for characterizing yarns. This new tool, in combination with such stochastic methods as Poisson cluster and extreme value models, would provide a better data analysis and decision making system suitable for on-line control environments.

CURRENT PROGRESS:

A. Experimental

We obtained 15 different kinds of 16/1 Ne open-end yarns produced from different spinning frames under identical process conditions. The samples ranging in CV from 15-17% were mechanically conditioned under a standard atmosphere for a month. Finally, the samples for each yarn were tested by using Uster 3® and Zweigle G-580® Evenness Tester in order to compare the measures of yarn density profiles. As an example, Figure 2 displays the actual diameter profiles of a 17/1 ring-spun yarn measured by Zweigle G-580®.

B. Relation Between Mass and Diameter Measurements

During this study, an exciting discovery was made on the CV% differences obtained from optical and capacitor sensor systems. By examining the relationship between diameter and mass profiles, the optical and mass CVs were compared by employing a geometrical and statistical model considering the effects of the measuring field length. Since we are in the process of developing the new system mentioned above, the relationship between the two CVs from Uster 3® and Zweigle G-580® are of great significance. This is particularly important in light of the equivalent CV values normally obtained from the two measurement systems in spite of the four-fold difference in their measuring field lengths. The assumptions made for the comparison were as follows:

i) geometrical shape of a yarn cross-section is circular,
ii) density of a yarn is uniform along the yarn length, and
iii) segments of a yarn are independent of each other.

By definition, CV% of mass density can be expressed by Equation (1) in terms of the two sets of measures. Here, \( E(m) \), \( Var(m) \) and \( CV(m) \) stand for the expectation, variance and CV, respectively, of the yarn mass measured at a given field length. The same for the yarn diameter are expressed as \( E(d) \), \( Var(d) \) and \( CV(d) \).

\[
CV \ (m) = \frac{\sqrt{Var \ (m)}}{E \ (m)} \tag{1}
\]
The expectation of yarn mass can be expressed in terms of the diameter statistics as follows:

$$E(m) = E\left(\rho \cdot \frac{1}{4} \pi \cdot d^2\right) = \rho \cdot \frac{1}{4} \pi \cdot \{Var(d) + E^2(d)\}$$

(2)

where $\rho$ and $d$ are the density and diameter of a yarn, respectively. Under the assumption that the diameter values of a yarn are normally, independently and identically distributed, the variance of the mass can be expressed as

$$Var(m) = Var\left(\rho \cdot \frac{1}{4} \pi \cdot d^2\right) = \rho^2 \cdot \frac{1}{16} \pi^2 \cdot \{4 E^2(d) \cdot Var(d) + 2 Var^2(d)\}.$$ (3)

By combining Equations (2) and (3) with (1), the expression for CV(m) is obtained as follows:

$$CV(m) = \frac{CV(d) \sqrt{4 + 2 \cdot CV^2(d)}}{CV^2(d) + 1}$$ (4)

Figure 3 plots the relationship between the two CV’s based on optical and mass measurements. The result has shown that the optical CV% is lower than the CV% based on mass density when the measuring field lengths are the same. Now, the effect of the measuring field must be incorporated into the CV calculation in order to compare the two systems, Zweigle G-580® and Uster 3®. As known in literature, the measurement field lengths of the two systems are 2mm (Zweigle G-580®) and 8mm (Uster 3®), respectively [6]. Consequently, Zweigle G-580® is expected to provide a CV% roughly twice as large as that from Uster 3®. This can be shown, in Equation (5), to establish a functional relationship between the two CV’s from the two different systems:

$$CV(U) = \sqrt{\frac{Var(\frac{m_1 + m_2 + m_3 + m_4}{4})}{E(\frac{m_1 + m_2 + m_3 + m_4}{4})}} = \frac{\frac{1}{2} \sqrt{Var(m_i)}}{E(m_i)} = 0.5 \cdot CV(m_i)$$ (5)

where $CV(U)$ and $CV(Z)$ are CV’s of Uster 3® and Zweigle G-580®, respectively, and $m_i$ is the $i^{th}$ ($i = 1, 2, 3$ and $4$) 2mm segment within a 8mm yarn segment. Figure 3 plots a theoretical relationship between CV% obtained from Uster 3® and that from Zweigle G-580®. Interestingly, the values are very close to each other for most yarns. As a concrete example on the measuring field effect, 17/1 ringspun yarn samples of 1000m length was measured using two different sensors, and compared for their measured CVs obtained. As shown in Table 1, the CV’s from Uster 3® and Zweigle G-580® are found to be very close each other. Using the actual CV% from Zweigle G-580®, the expected CV% from Uster 3® was calculated by Equation (5), and the theoretically calculated values were compared to an actual values. As expected, the theoretical CV% of Uster 3® were close to the actual values.
C. Characterization of Yarn and Fabric Qualities Using Wavelet-Stochastic Hybrid Method

We applied a wavelet transform and stochastic models in order to represent the totality of the yarn characteristics by retaining a minimal amount of data without a significant loss in the information content. The stochastic models facilitated detection and identification of spinning faults, while the use of wavelet analysis provided a compact representation of signal features without a significant loss of information. The algorithm for combining the wavelet and stochastic methods to continuously monitor the process consisted of performing them sequentially on-line. The procedure was as follows:

**Step 1:** Capture the yarn diameter signals continuously up to first 50m.

**Step 2:** Count the characteristic measures such as occurrence of neps/thick places, length of thick places, and amplitudes of neps/thick places within the segment.

**Step 3:** Compare the parameters for the current signal with the normal parameter set. For normal parameter set, discard all the data. If there is a significant change in a current parameter set, record the parameters and location of the current sub-block.

**Step 4:** Perform wavelet transform for the abnormal parameter set. Record the transformed coefficients with the parameters and the location.

**Step 5:** Proceed to the next sub-block, and repeat steps 1 through 4 to produce a yarn density profiles.

The on-line monitoring system based on the hybrid monitoring scheme has been applied to an actual yarn manufacturing process in order to simulate the performance of the system under a production environment. Ten yarn packages were measured on a Shlafhorst® open-end spinning machine at normal production conditions, providing data for a total of length of 250,000m, or 25,000m for each package. The massive amount of data could be reduced to a small fraction consisting of i) a set of statistical parameters for normal sub-blocks, ii) sets of statistical parameters on abnormal sub-blocks for characterizing yarn and fabric defects and for providing their time-domain addresses, and iii) wavelet coefficients for abnormal sub-blocks. Although it depended on the variability of each signal, the reduction rate was close to 1 to 100,000 in the example at which 100 spindles could be monitored for 10 hours by storing only a small fraction of the data. The space required was only 5 KB. The performance of the reduction system was evaluated by comparing the original signals and the virtual signals generated by simulating fabric images. Figure 4 compares two fabric images produced from two yarn density profiles. The figure also shows that the virtual signals generated from the reduced data retained almost the same quality features of the original signals.

**PROSPECTS:**
1. Prospects are excellent for developing a multi-sensor, simultaneous yarn quality measurement system in the near future. The opto-capacitive system will measure the yarn diameter and mass density simultaneously and combine them in spatial domain to create a new uniformity measure (to be named). The matching errors caused by tension variation during yarn transport will be minimized by a specially designed control mechanism. The system, if successfully built, will be the first of its kind with a built-in signal processor.

2. The density profiles obtained from the system will be analyzed by wavelets. The wavelet-based multi-resolution analysis will validate the usefulness of the new measurement system by linking the measured yarn characteristics to visual qualities of the resulting fabrics through the spatial decomposition of yarn density signals.

3. Using the wavelet-stochastic hybrid method developed, we can store only a portion of the original signals for either control purposes or graphical representation of the visual qualities of the yarns and the resulting fabrics. The hybrid method will be incorporated into the simultaneous yarn measurement system under development for future on-line quality control of spun-yarn production. As a final product, a stand-alone yarn quality measurement/characterization system can be envisioned.

LITERATURE CITED:

Figure 1. Two individual systems for diameter (a) and mass (b) measurements
Figure 2. Diameter profiles of a 17/1 ringspun yarn used (CV%:15.7)

Table 1. Comparison of CVs from two measurement systems

<table>
<thead>
<tr>
<th>Systems</th>
<th>Measuring Field</th>
<th>Actual</th>
<th>Theoretical*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zweigle G580®</td>
<td>2mm</td>
<td>15.4 - 15.6</td>
<td>-</td>
</tr>
<tr>
<td>Uster 3®</td>
<td>8mm</td>
<td>14.8 - 15.1</td>
<td>15.0 - 15.3</td>
</tr>
</tbody>
</table>

* the values calculated based on Equation (5)
Figure 3. Theoretical relationship between two CV%\text{s} based on optical and mass sensors: a) before and b) after of measuring field correction.
Figure 4. Comparison of simulated fabric images from a) original yarn density signals and b) simulated yarn densities with 99.9999% (1 to 100,000) reduction rate