APPROACHES OF USING THE BEARD TESTING METHOD TO OBTAIN COMPLETE FIBER LENGTH DISTRIBUTIONS OF THE ORIGINAL COTTON SAMPLE

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Abstract

The fiber testing instruments such as HVI can rapidly measure fiber length by testing a tapered fiber beard of the sample. But these instruments that use the beard testing method only report a limited number of fiber length parameters instead of the complete length distribution that is important for better evaluation of the original cotton sample for a customer's specific needs. We have conducted research to get a complete length distribution of an original cotton sample. The research included the statistic descriptions of cotton fiber length distributions, the partial least squares method, the staple diagram method, and the experimental procedures and data. The results indicate that the models and procedures we adopted have a good potential for obtaining the original cotton fiber length distribution from the beard test.

Introduction

The beard testing method is used for rapidly measuring a cotton sample's length by scanning a fiber beard instead of individual fibers. Present devices using the beard testing method can accurately measure several length parameters, such as Mean Length, Upper Half Mean Length, and Uniformity Index, but not the complete length distribution of the original sample, which is important for better evaluating a cotton sample's quality and suiting customers' different needs. For example, the length distribution can be used for computing any specific length parameter for optimizing the prediction of a particular yarn property (Cai *et al* 2011), and the change of the length distribution curve may indicate impacts from cotton processing (Krifa 2008).

Our research objective is to obtain the complete original fiber length distribution from the beard testing method. This is a challenging task since the measured length distribution is shifted from the original sample during the measurement (Suh *et al* 2006, Cai *et al* 2009). The early beard theory developed by Hertel had several assumptions, such as that the probability of each individual fiber being sampled is length-biased, the fiber clamp is very thin, and the undetectable portion held inside the clamp is negligible (Hertel 1940). Not all the assumptions can be satisfied in modern systems. Our investigations indicate that the sampling process is not length-biased (Cai *et al* 2010), and neither is the hidden portion negligible (Cai *et al* 2009). We have conducted investigations on comprehensive aspects in this area, which is aimed to get the complete length distribution of the original sample. We have developed two new methods for obtaining the length distributions of the original sample.

When preparing a fiber beard for length measurement, after using a fiber comb to make the beard, not the entire fiber beard can be scanned. A portion of the beard is hidden inside the comb; the rest of the beard is projecting out of the comb and actually scanned. Our research has shown that the length distribution of the original sample is very different from that of the projecting portion (Cui *et al* 2009). Therefore, to achieve the objective of getting the complete length distribution of the original sample, new approaches are needed to infer the length distribution of the original beard with that of the projecting portion.

New Approaches

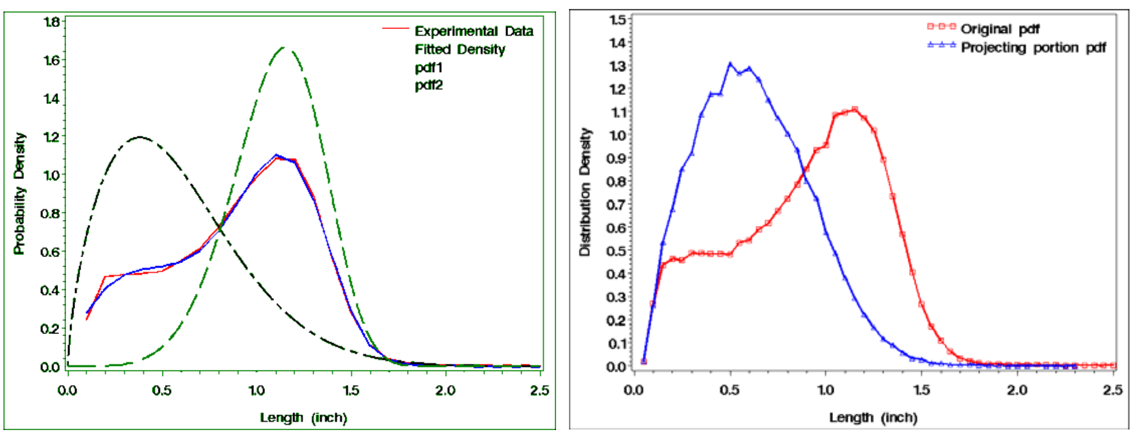
We developed two approaches to obtain the length distribution of the original sample from that of the projecting portion. One is the Partial Least Squares (PLS) regression method (Belmasrour *et al* 2011). By using AFIS to establish a database of individual fiber lengths, we obtained the five-parameter mixed Weibull functions of the length distributions, which are related to the beard testing method (Cui *et al* 2009). The density function of Weibull distribution is shown in Equation 1. Equation 2 and Figures 1a show the mixed Weibull density function of the original sample. The projecting portion's length distributions can also be expressed by using the five parameters (Equation 3). The difference between the probability density functions of the original beard and that of the projecting portion is shown in Figure 1b.

$$f(x;\ \lambda, \theta) = \lambda\, \theta\, x^{\lambda-1} e^{-\theta x^{\lambda}}, \quad x>0, \quad \lambda>0, \quad \theta>0 \tag{1}$$

$$f(x;\ a,\ \lambda_1, \theta_1,\ \lambda_2, \theta_2) = a f_1(x;\ \lambda_1, \theta_1) + (1-a) f_2(x;\ \lambda_2, \theta_2) \tag{2}$$

$$f(x;\alpha',\lambda_1',\theta_1',\lambda_2',\theta_2') = \alpha' f_1(x;\lambda_1',\theta_1') + (1-\alpha') f_2(x;\lambda_2',\theta_2') \tag{3}$$

In order to infer the parameters in Equation 2 from Equation 3, we used Partial Least Squares (PLS) regression method instead of ordinary least squares methods. Ordinary least squares method did not yield satisfactory solutions because of relatively small sample size and multicollinearity of the data. On the other hand, the PLS method better handled these difficulties, and its solution provided the estimations of the fiber length probability density function's five parameters of the original beard from those of the observed projecting portion. Different fiber length parameters can be calculated from the probability density functions.



a b

Figure 1. (a) The probability density function of a cotton sample, which can be fitted by using a mixed Weibull function that contains two Weibull functions and five parameters. (b) The probably density functions of the original sample and the projecting portion.

The other approach we developed is to use staple diagrams to infer length distributions. A staple diagram is the contour formed when all individual fibers in a cotton sample are aligned with all leading ends at one straight line and sorted from the shortest to the longest, as depicted in Figure 2. From Figure 2 it can be seen that the staple diagram of the projection portion is very different from that of the original sample.

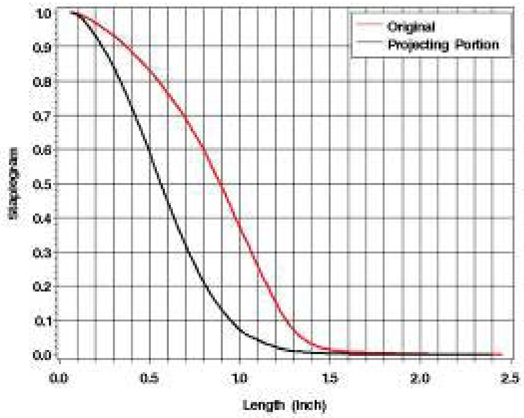


Figure 2. The staple diagrams of the original fiber beard and the projecting portion

A cotton beard's staple diagram contains complete information of fiber length distribution. It is directly related to its fibrogram, cumulative function, and probability density function. We developed a model to compute the staple diagram of original sample from that of the beard's projecting portion. Weibull distribution cumulative functions were used to describe the staple diagram discrepancies between the original beard and the projecting portion.

At first we generated the staple diagrams from AFIS measured individual fiber lengths. We further directly worked on beard scanning signals to generate the staple diagrams of the projecting portions, and then using them as inputs, and then the staple diagram method was implemented to compute the staple diagrams of the original cotton beard. Different fiber length parameters can also be calculated from the staple diagram method. Results showed good agreements with AFIS generated results, which were used as the reference.

Results

Figures 3 a and b show the PLS results. The original samples' probability density functions from PLS regression (dash lines) are plotted against those from experimental data (solid lines). The results show a good match between the PLS and experimental results.

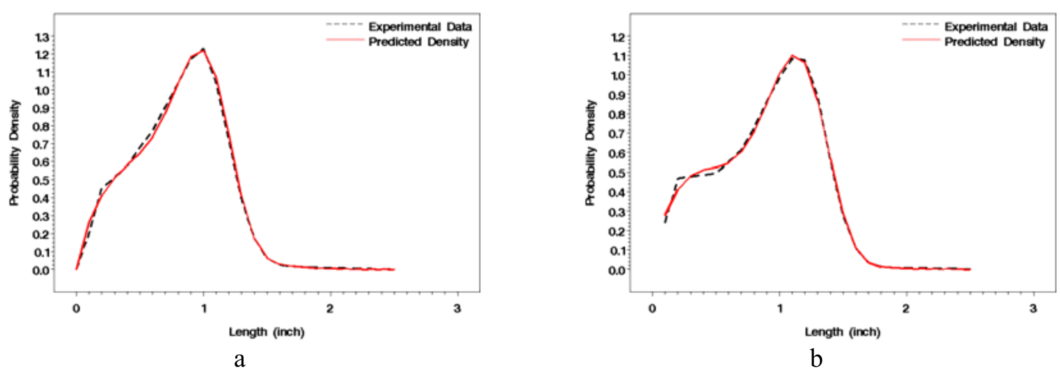
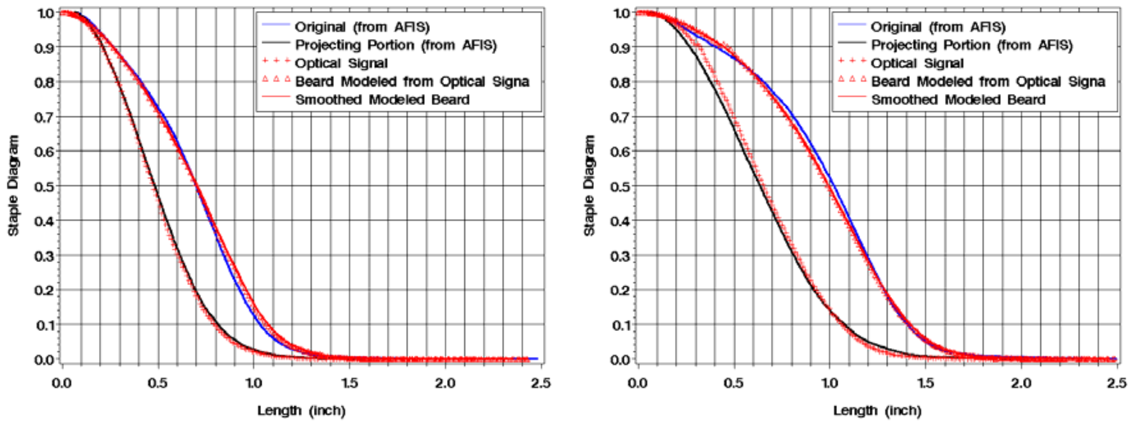


Figure 3. Probability density function plots from PLS results and experimental data (a) MLw 0.95 inch, UQLw 1.13 inch; (b) MLw 0.92 inch, UQLw 1.29 inch

Figures 4 a and b show the staple diagrams. In each figure, five staple diagrams are displayed: 1) the staple diagram of the beard's projecting portion constructed using AFIS data; 2) the staple diagram constructed using optical signal; 3) the staple diagram of the original sample constructed using AFIS data; 4) the modeled staple diagram of the original sample; and 5) the smoothed staple diagram of the model, which is computed by using the local regression algorithm. In both figures, the smoothed modeled staple diagrams of the original sample closely match the original sample staple diagrams constructed from AFIS data.



a b

Figure 4. Staple diagrams of the original beard and the model result (a) MLw 0.81 inch, UQLw 0.97 inch; (b) MLw 1.12 inch, UQLw 1.32 inch

From the above PLS and staple diagram method, we also computed the length parameters and compared them to experimental results. These parameters are Mean Length by weight (MLw), Mean Length by number (MLn), Upper Half Mean Length (UHML), Lower Half Mean Length (LHML), Upper Quartile Length by weight (UQLw), Upper Quartile Length by number (UQLn), Shorter Fiber Content by weight (SFCw), and Short Fiber Content by number (SFCn). The comparisons are listed in Table 1. The average differences (absolute values) of these length parameters of both approaches indicate that the parameters computed from the PLS regression method and staple diagram method agree with the parameters from experimental data very well. In addition, these differences show that the PLS method had slightly better results for parameters which were mainly decided by longer fibers in a beard, such as UQLw and UHML. On the other hand, for parameters that characterizing short fibers such as SFC and LHML, the staple diagram model can make better prediction. This indicates that the two methods can be applied simultaneously to improve the accuracy of the estimation of length parameters.

Table 1. Differences between length parameters computed from models and experimental data (length unit: inch)

Parameter	SFCw	SFCn	UQLw	UQLn	MLw	MLn	UHML	LHML
Average diff. (PLS regression)	0.9%	2.6%	0.014	0.013	0.01	0.02	0.015	0.024
Average diff. (staple diagram)	0.7%	1.7%	0.022	0.015	0.014	0.012	0.029	0.014

Conclusions

Present cotton quality measuring devices using the beard testing method can accurately measure several length parameters but not the complete fiber length distribution. The complete length distribution is important for better evaluating a cotton sample's quality and suiting customers' different needs. We used the mixed Weibull function to describe fiber length distributions' probability density functions. We developed a new PLS regression approach to estimate the Weibull function's parameters of the original beard from those of the projecting fiber portion. We also developed an approach to model the staple diagram of the original beard from that of the projecting portion. The staple diagram method was applied directly on optical scan signals to obtain the original staple diagrams. Comparisons between length distribution results from the approaches and those from experimental data show good agreements. Both approaches can be used to compute different length parameters to suit customers' needs. Results indicate that the proposed approaches are very promising for obtaining fiber length distributions from rapidly testing a fiber beard and thus improve the current beard methods and devices.

Disclaimer

Names of companies or commercial products are given solely for the purpose of providing specific information; their mention does not imply recommendation or endorsement by the U.S. Department of Agriculture over others not mentioned.

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