A STATISTICAL ANALYSIS OF THE INTRA-SAMPLE DISTRIBUTION AND VARIATION OF COTTON COLOR AND ITS APPLICATION

Yiyun Cai,
Louisiana State University
Baton Rouge, LA
Xiaoliang Cui
James Rodgers
USDA ARS, SRRC
New Orleans, LA
Vikki Martin
Mike Watson
Cotton Incorporated
Cary, NC

Abstract

Cotton color's intra-sample distribution and variation may indicate the variation of fiber quality that influences the quality of textile product. Currently the colorimeter method for measuring cotton color provides a cotton's overall color grade; its result does not include information about the intra-sample color distribution and variation. We conducted an investigation using color image analysis and statistical analysis to study the intra-sample distribution and variation of cotton color. We present theoretical and experimental work of the study, and the statistical aspects of the intra-sample distribution and variation of cotton color and the applications.

Introduction

Color is one of the most important properties in cotton classing and trade. Cotton color, as indicative of pigments in a natural product, is a property of a collective representation of individual fibers. Therefore it has a distribution and variation even within the same cotton sample (intra-sample variation) even though the overall inter-sample variation could be very small. Cotton color's intra-sample distribution and variation may be associated to the variation of fiber quality that influences the quality of textile product.

The colorimeter principle is widely used to measure cotton color (*Rd*, and *+b* values). It provides the sample's overall color grade, however the reported result does not include information about the color distribution and any variation within the sample. There have been many previous studies that focused on methods or algorithms for improving the measurement of the overall color grade of a cotton sample (Nickerson 1946, Kang and Kim 2002, Xu *et al* 2002). We conducted an investigation using color image analysis and statistical analysis to study the intra-sample distribution and variation of cotton color. This paper discusses the theoretical and experimental studies, and the statistical aspects of the intra-sample distribution and variation of cotton color and the applications.

Methods

For image analysis, cotton samples were scanned by using a color scanner. Image resolution was 400 dpi, images were stored in 48-bit sRGB format. Samples were placed on the scan window of a 4.5" × 4.5" size. A 5 kg (11 lb) weight was pressed on top of the sample. For each image, a 3.5" × 3.5" area was selected to simulate the size of the HVI color window. HVI tests were also conducted to obtain overall color grades as references. The sRGB values of each pixel are used as inputs to compute *Rd*, *+b* values and then color grades; the method for computing the *Rd*, *+b* values and color grade is shown in Figure 1.

Figure 1. Computation of *Rd*, +*b* values and color grade from scanned images

The 3.5" × 3.5" area was divided into sub-areas, the sub-area size ranges from ½" × ½", ¼" × ¼", to a single pixel. Each sub-area's Rd and +b values were computed and its grade was determined by searching a color grade look-up table provided by USDA AMS (Figure 2).

Figure 2. Computation of *Rd* and +*b* distributions

Results and Discussion

Comparison of Intra-Sample and Inter-Sample Variations

Results from color image analyses and HVI color measurements were used to study *Rd* and +*b* values' inter-sample variation, which is the overall color variation obtained from five different reps of one cotton. Results from both color image analyses and HVI color measurements indicated that the average inter-sample variation (CV: coefficient of variation) of *Rd* and +*b* values were very small. Results also indicated that +*b* variations were higher than *Rd* variations.

Table 1. Inter-sample Rd, +b variations of HVI and image analysis results

Methods	Rd_CV_{inter}	$+b\_CV_{inter}$
HVI	0.65%	1.92%
Scanner	0.82%	2.50%

Results from color image analysis indicated that the intra-sample variations of *Rd* and +*b* values were much higher (intra-sample CV for Rd can be >7%, and >15% for +b) compared to inter-sample variations. Intra-sample color variations displayed evident spatial characteristics over the color grade chart. For example, for sub-area size of 0.25" × 0.25", a 3.5" × 3.5" measurement window will have196 sub-areas. The grades of these sub-areas span over several grades on the color grade chart, while overall grades of the sample usually concentrate very closely on the same grade.

Difference of Intra-Sample Color Variations and Distributions between Samples of the Same Overall Grade

Two samples can have the same overall color grade but different intra-sample *Rd* and +*b* variations, as shown in Figure 3. These two samples have the same overall grade, but the CVs of their Rd and +b are different (Table 2).

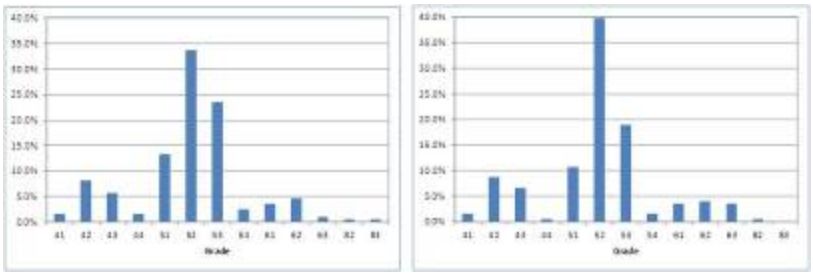
Sample #1 Sample #2

Figure 3. Two samples that have the same overall color grade

Table 2. Rd and +b variations and overall grades of two samples

Sample	*Rd*	CV_*Rd*	*+b*	CV_*+b*	Grade
#1	65.51	5.1%	9.21	15.0%	52-1
#2	65.50	4.8%	9.18	11.5%	52-1

Although the two samples have the same overall grade, image analysis revealed that the two samples have different intra-sample color grade distributions and variations. Figure 4 shows the histograms of the grades of the samples, apparently they are different. Therefore developing a proper parameter or a combination of parameters characterizing the intra-sample color variation can be helpful for better evaluating color properties.



Sample #1 Sample #2

Figure 4. Comparison of color grade histograms of samples #1 and #2

Using Bivariate Normal Distribution to Study the Intra-Sample Color Distribution and Variation

For further quantitatively study the intra-sample color distribution, mathematical descriptions of the variations need to be established. It is promising that the bivariate normal distribution function can be adopted. This function considers *Rd* and *+b* distributions together:

$$\Phi(Rd,+b)=\frac{1}{2\pi\sigma_{Rd}\sigma_{+b}\sqrt{1-\rho_{Rd,+b}^2}}\exp\left\{-\frac{1}{2(1-\rho_{Rd,+b}^2)}\left[\frac{(Rd-\mu_{Rd})^2}{\sigma_{Rd}^2}+\frac{(+b-\mu_{+b})^2}{\sigma_{+b}^2}-\frac{2\rho_{Rd,+b}(Rd-\mu_{Rd})(+b-\mu_{+b})}{\sigma_{Rd}\sigma_{+b}}\right]\right\} \quad (1)$$

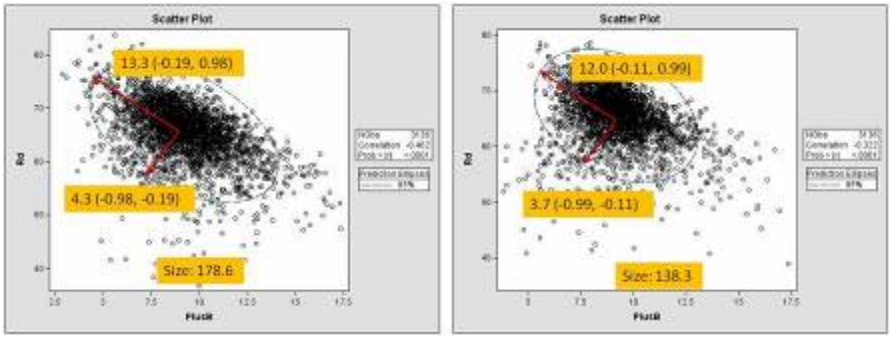
Its covariance matrix is

$$C=\begin{bmatrix}\sigma_{Rd}^2 & \rho_{Rd,+b}\sigma_{Rd}\sigma_{+b}\\ \rho_{Rd,+b}\sigma_{Rd}\sigma_{+b} & \sigma_{+b}^2\end{bmatrix} \quad (2)$$

in which μ_{Rd} and μ_{+b} are the means of *Rd* and *+b* respectively; σ_{Rd} and σ_{+b} are the standard deviations of *Rd* and *+b* respectively; $\rho_{Rd,+b}$ is the correlation between *Rd* and *+b*.

Parameters generated from the bivariate normal distribution can be used to investigate intra-sample distribution and variation properties. The distribution prediction ellipses' locations, shapes, orientations, and sizes are different and can be analyzed quantitatively from the covariance of *Rd* and *+b* (Figure 5). Consequently, although two samples

may have the same overall color grade (reflected by the centers of the ellipses), the effects from their different intra-sample *Rd* and *+b* variations can be clearly compared by using the geometrical values of their distribution ellipses, such as the size of the ellipses, the lengths and orientation of the two axis. These values can be utilized to evaluate the color quality issues associated with the intra-sample distribution and variation.



Sample #1 Sample #2

Figure 5. Comparisons of the two samples using bivariate distribution

Conclusion

A cotton's color has a distribution and variation within the same sample (intra-sample variation) even though this cotton's overall inter-sample color variation could be very small. Scanned color images were used to compute samples' *Rd* and *+b* values. The results were well associated to HVI measured *Rd*, *+b* values. Color grades were determined by using the computed *Rd* and *+b* values consequently. For a cotton, the inter-sample color variation is small, but the intra-sample color variation is much higher. The intra-sample color grade has a distribution that spans over a large range of color grades on the color chart. The intra-sample color grade histogram indicates that cottons with the same overall color grade may have different intra-sample *Rd* and *+b* distributions and variations. Therefore at least one proper parameter or a combination of parameters characterizing the intra-sample color variation is helpful for better evaluating color properties. The intra-sample color distribution can be described by using the bivariate normal distribution. The intra-sample distributions' locations, shapes, orientations, and sizes can be quantitatively analyzed, consequently be evaluated with regard to their impacts on cotton color quality.

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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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