COLOR GRADING OF COTTON-MEASUREMENT (PART I)

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Abstract

Spectrometer measurements of the color of cotton, based on CIE Standards, were compared with High Volume Instrumentation (HVI) methods. Color imaging and spatial interpretation were examined with the intent of demonstrating the importance of color uniformity, trash content and yellow spot on classer color grading. Agreement is enhanced between HVI color grading and the cotton classer by the inclusion of the CIE color space redness parameter a*, trash content, and yellowness variability.

Introduction

Cotton grade is composed of three factors - color, leaf, and preparation. Although normally white, exposure to weathering and the action of microorganisms causes white cotton to lose brightness and became darker and bluish gray. Cotton may also become discolored or spotted by the action of insects, fungi, and soil stains. Furthermore, an early frost may cause cotton to acquire a yellow color that varies in depth. In the grading of U.S. Upland cottons, all of these color differences are recognized, divided into categories and described. The varying amount of yellow color found in cotton forms the basis for defining the color groups used in the standards for grading Upland cottons. These color groups are: White, Light Spotted, Spotted, Tinged, and Yellow Stained. The Plus, Light Gray, and Gray designations are used to indicate different combinations of color and leaf relative to those normally found in the White grades.

The HVI colorimeter measures grayness (Rd) and yellowness (+b) using photo-detectors and color filters. This system gives consistent average color measurement, only Moreover, redness (+a) is an ignored parameter in current HVI colorimeters. Because of these limitations of the colorimeter, the measurement of color agrees only partially with human visual inspection. The cotton classer is able to integrate much more color information than can the limited capabilities of the instrumentation. Agreement on color grade between HVI and cotton classer currently stands at approximately 70%. The purpose of this study is to improve the agreement between cotton classer and HVI color measurement by incorporating both standardized spectral analysis and color image analysis.

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Background

Two types of instrumentation used in color measurement are the spectrometer – full spectral analysis - and the color filter method where regions of spectra are instrumentally integrated by placement of filters between reflected light and optical sensor. The first of these methods – spectrometer - measures color based on the entire visible spectrum of the sample. The results of the spectral analysis are traceable to standards established by CIE (Commission International de l'Eclairage). Color measurements are reported in CIE color space as L* (lightness), a* (red-green), and b* (yellow-blue).

The filter-type instrumentation measures color based on the detection of reflected light signals passing through red, blue and green filters. The entire visible spectrum is not sampled in a standardized way and, therefore, is not as accurately referenced as the spectrometer. Nonetheless, it is a much more rapid method of color measurement and is the general basis by which modified HVI colorimeters might be used for cotton grading. Cotton color grading is in terms of Rd (reflectance) and +b (yellowness), with the added factor of +a (redness) not presently included. In order to accurately measure the mean values of reflectance (L* or Rd), yellowness (b* or +b), redness (a* or +a), we have interfaced an HVI color head to a fiber-optic spectrometer (Ocean Optics S1000). Comparative relationships between spectrometer and filter approaches are obtained and discussed using computer simulation techniques.

The color measurements of the two preceding methods are spatial averages and do not provide information on color uniformity, texture, and trash/yellow spot on the surface of the cotton sample. To obtain this information, a color scanner with CCD imaging can be used to survey the sampled area pixel-by-pixel.

Calculation of Tristimulus Values

The instrumental measurement must ultimately be directly associated with the response of the human eye, with its receptors for the perception of color. The color sensation can be matched by the mixing of three colored lights. Using this technique, standard observer functions are determined and used in conjunction with standard light sources to determine the amounts of primaries to match an observed reflected light color. Using them, the amounts of the primaries X, Y, Z, necessary to match a spectral color can be calculated. These tristimulus values X, Y, Z describe color perception, and the calculation of the tristimulus values is the first step in designing standardized color measurement instrumentation.

The steps for calculation of tristimulus values are simple. First, the light that would fall on the eye is determined. It is the product of the spectral power distribution of the illuminating light source S(λ) and the reflectance function R(λ) of the sample, summed over the visible spectrum. The amounts of the primaries for each wavelength is summed up to get the whole amount of light from the primaries needed to match the sample. Again, this the amount of light which is sent by the sample to the normal observer's eye corresponding to the sensitivity (observer functions) of the receptors in the eye - $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$. These three integrated stimuli are the tristimulus values X, Y, Z. The equations for calculating the tristimulus values corresponding to the description then become:

$$X = \sum S(\lambda) \times R(\lambda) \times \bar{x}(\lambda) \tag{1}$$

$$Y = \sum S(\lambda) \times R(\lambda) \times \bar{y}(\lambda) \tag{2}$$

$$Z = \sum S(\lambda) \times R(\lambda) \times \bar{z}(\lambda) \tag{3}$$

The tristimulus value Y has a special significance - a measure of the lightness of the sample. The tristimulus values are standardized so that ideal white has the value Y=100 for every illuminant and every observer.

Calculation of the L*, a* and b* Values

In 1976, CIE recommended two color spaces for practical use, CIELUV and CIELAB system. In most cases the CIELAB formula is used.

$$L^* = 116\left(Y/Y_n\right)^{1/3} - 16 \tag{4}$$

$$a^* = 500\left[\left(X/X_n\right)^{1/3} - \left(Y/Y_n\right)^{1/3}\right] \tag{5}$$

$$b^* = 200\left[\left(Y/Y_n\right)^{1/3} - \left(Z/Z_n\right)^{1/3}\right] \tag{6}$$

where L* = lightness,
a*, b* = chroma coordinates in the CIELAB color space. a* is a measure of redness or greenness, b* is a measure of yellowness or blueness, and X_n, Y_n, and Z_n are the tristimulus values for ideal white and the illuminant-observer combination used.

Color Scanner System

The three primary colors, red (R), green (G), and blue (B) are incorporated into instrumented color systems and this RGB system is the basis of the color scanner. The CIE spectral primary system RGB cannot yield all possible reproducible colors, but CIE has proposed the XYZ primary system having hypothetical coordinates X, Y, Z. The XYZ primaries are linearly related to the RGB primary system. The CIE L* a* b* system, introduced earlier, is connected to the RGB primary system. In color image analysis, L*, a* and b* can be computed for each pixel using equations 4 to 6.

Color Uniformity, Variance in Uniformity, Texture, Trash and Yellow Spot

The current HVI color grading system is based on average values of color. In reality, color uniformity is important to color grading and should be a quality attribute in a color grading system. Color uniformity can be handled in imaging systems, with appropriately defined parameters such as variance of L*, a* and b* with respect to a cell unit. We have selected a cell size consisting of 32 pixels along the side as most representative of visual eye response.

Another important visual characteristic is texture. Application of texture analysis in textiles - defined as a measure of image coarseness, smoothness and regularity - can be found in recent publications on carpet and fabric evaluation. Because human visual perception is sensitive to second-order statistics, gray level co-occurrence matrices (GLCM) and gray level difference histograms (GLDM) are widely used in texture analysis. In this study, we consider only GLDM for texture analysis because of its performance and speed. From this are obtained descriptors for gray level, variance, and contrast. Contrast, in particular, is selected to describe the texture of cotton samples because it is sensitive to human perception.

Image processing also encompasses a broad range of operations to increase the visibility of specific features or to acquire particular descriptive information on these features. A process called smoothing is applied to an image to optimize edge sharpness of features. This sometimes involves introduction of median filters, in which the gray level of each pixel is replaced by the median of the gray levels in a neighborhood of that pixel.

In contrast to grey-level images, binary images can be obtained to distinctly define features like trash. A binary image, obtained through thresholding techniques, is distinct from a gray-scale image because each point is either white or black. Thresholding provides a guide for which points lie within the features of interest, thereby separating a feature from background. For this reason, binary images are often more suitable for dimensional measurement than are gray scale images.

If one applies thresholding in L*, a* and b* color space and combine the results into one image, an image is obtained showing the objects of trash and yellow spots. The labeling process defines a region of interest and, for each region of interest, a set of features can be selected which will be used for recognition of trash and yellow spots. This feature set includes L*, a*, b*, area, and shape factor for each object. Subsequently, fuzzy reasoning is incorporated for trash / yellow spots classification. After each object has been classified as yellow spot or trash, the percent area of yellow spots and trash can be computed by the ratio of total spots area and the total imaging window area. Other measurements can be made, such as size distribution of the trash and yellow spots and the features of each object.

Experimental

Instrument Setup and Samples

The cottons examined make up a box of twelve color-check cottons. This cotton sample set covers a wide range of reflectance Rd from of 57 to 80 and yellowness +b from 5.8 to 14.4, as measured by accepted HVI colorimeter.

Light source and illumination angle have significant influence on color measurement. In this study, the primary interest is to examine and modify appropriately the color grading system of the HVI, keeping the illumination components of the system. The HVI color head used comprises two light sources positioned at 45° to the surface of the cotton sample. A fiber optic cable is mounted to receive the reflected light perpendicular to the sample. The other end of the cable is connected to an Ocean Optics S1000 fiber-optic spectrometer, into which the light is dispersed across a linear array of 1024 CCD detectors. The software (*SpectraScope*™) for color applications provides a precise way to perform standardized color measurement using the basic principles and techniques defined by CIE. The first set of values derived constitute our tristimulus values using equations 2-4. From these values, the uniform color space coordinates, known as CIELAB color space, are calculated using equations 5-7.

A low cost color scanner (Mustek 600 II EP) was used for color image analysis. The flatbed color scanner provided 24-bit color mode scanning capable of capturing up to 16.7 million different colors. Optical resolution is 300x600 dpi. The scanned images were processed using a Pentium 166 MHz PC and special software developed for color measurement, texture analysis and trash/yellow spots detection. The samples were scanned over an area of 3x2.5 inches squared. The software developed computed L*, a*, b*, for each pixel in the image and the results were stored as three images representing L*, a*, b*.

Results and Discussion

Color Measurement with Spectrometer and the Importance of Redness

The 12 samples ranged considerably in grayness and color. Lightness L* ranges from 84 to 96.7. Redness a* ranges from –0.11 to 2.43, and yellowness b* ranges from 7.9 to 18.0. The results are listed in Table 1 and plotted in Figure 1.

More specifically, C1 is a very white cotton and is very uniform when viewed in daylight. The results show C1 has the highest value in L*, low redness and moderate yellowness. When the spectrum of C1 was compared with a white reference background, the two spectra were very close in the orange to red region. In the blue to green region, however, the spectrum from C1 displayed lower energy than reference white and this causes the sample to appear a little yellowness.

When sample C7 was compared against sample C4, it was observed that the two differed little in grayness, but showed substantial difference in color at short wavelengths. Visually, sample C7 appeared with both the highest yellowness and redness of all the 12 cottons. This is clearly demonstrated by high a* and b* values, as shown in Figure 1. In addition, sample C4 showed a greenish tint and the spectrometer measure of a* was very low, as expected. Sample C4 showed higher energy from 400 nm to 600 nm (blue to yellow region) while C7 displayed higher energy above 650 nm (red region). C5 gives the lowest yellowness value from spectrometer, but C4 is very low also. Both agree with visual perception as well.

Samples C7 and C8 are good examples of the importance of the redness (a*) measurement. Both samples have very similar grayness and the difference in yellowness is not extremely disproportionate. The difference in redness, however, is significant. As can be observed, a* of sample C7 equals that of C8. These two samples did show significant redness difference visually. The examples given here strongly indicate that using grayness and yellowness alone probably do not provide sufficient information in HVI color grading. Redness a* may be useful to a more precise characterization of color and, hence, probably should not be ignored in color grading as in the past.

Correlation between Spectrometer and HVI Color Measurement

As a final comparison and connection with HVI color grading, there is presented (Fig. 2) plots and correlation between HVI Rd, +b and spectrometer L*, b*, respectively. The R^2 values are high for both (0.98 for Rd and 0.99 for +b). However, HVI color grading between HVI and cotton classer continues to agree only about 70% of the time. To raise agreement, it is necessary to show how a*, and some additional color parameters, can and must be taken into account.

Color Uniformity and Variance Spectrum

Color uniformity was measured by variance in CIELAB space. Figure 3 shows the variance in L*, a* and b* space for all 12 samples. Samples 1, 2 and 3 are white and uniform samples. The results show these three samples have lower L* and b* variance. Samples 9, 10, 11 and 12 are dirty cottons and the variances are proportionately higher. Sample 7 is a very yellow cotton. It shows high variance in b* space, but quite low variance in L* space. In a* space, sample 6 has the lowest variance value in redness. This sample visually appears gray and shows the lowest mean yellowness. Sample 11 shows the highest variance in redness, and it also has a high variance in both grayness and yellowness.

A contrast spectrum in L*a* b* space was also obtained on a few selected samples. First, there were no obvious peaks in these curves, and this implies that there were no periodic texture patterns in these samples. Second, no significant difference was seen in either the horizontal or vertical directions. This indicated that color variation is isotropic. Generally L* ,a* and b* contrast increases separately in both horizontal and vertical directions with increased pixel separation. This increase is more pronounced with L* than for b*. Beyond a distance of 80 pixels, the rate of increase in L* decreases. As a result, horizontal contrast at a distance of 80 pixels (about 12 mm) was selected as a texture measure for a grading system.

Figure 4 plots the contrast of L* and b* for all 12 samples. Samples 1, 2 and 3 have low contrast in both lightness and yellowness as expected. Sample 5 and 6 have higher contrast in lightness, but lower contrast in yellowness. These two cottons show no yellowness or yellow spots problems. Sample 7 shows high contrast in yellowness but low contrast in lightness. This latter sample is a yellow cotton with very little trash content. Samples 10, 11 and 12 show high contrast both in lightness and yellowness as expected for low grade dirty cottons.

Percent Area of Yellow Spots and Trash

Figure 5 plots the percent area of trash and yellow spots for these 12 samples. Samples 1, 2 and 3 are clean white cottons and show almost no trash and yellow spots. Sample 10 shows the highest trash content, but low yellow spots content. Sample 12 has both a high level of trash and yellow spots content. These results agree with the visual perception of the cottons. Samples 7 and 11 visually show high yellow spots content, but low trash content.

When the results from the spectrometer are combined with the measurements obtained from color imaging, one is able to describe the 12 samples much better. Sample 1 is a white cotton with highest lightness, medium yellowness and low redness; color uniformity is very good with low variance and contrast in color space; it is a very clean cotton without trash and yellow spots. Sample 4 is a little greenish and medium lightness cotton; its appearance shows low variation in yellowness, but a medium degree in lightness variation; it has a little trash but no yellow spots. Sample 7 is a very yellow and red cotton; it has high variation in yellowness and redness, but low variation in lightness; it shows a high degree of yellow spots, but is low in trash. Sample 10 is a very dirty cotton with lowest lightness and its lightness variation is very high, as is its yellowness variation. It has the largest amount of trash and some yellow spots. Sample 11 is a yellow cotton with high redness, also. It has very high variation in redness and yellowness, as well as having some trash and a high degree of yellow spots. Sample 12 is both high in trash and yellow spots; its variation in color is not low either.

Conclusions

Spectrometer measures of color, based on CIE methods, use the distribution functions of the entire visual spectrum. It is the preferred approach for color measurement and is the standardized procedure for CIE color measurement. Redness a* is ignored in current color measurement. For better color differentiation, we should include it in HVI color measurement. Results from computer simulation show that we might achieve satisfactory color measurement for L* and b* by selecting filters that are close to the standard observer. But this may not be easy for a* for a three-filter system. A more sophisticated filtering may be required, but this is possible and can be implemented in HVI systems engineering.

Color uniformity can be described by variance and contrast in CIELAB space. L*, a* and b* color space coordinates provide the information for trash and yellow spots separation. Using color variance and contrast, yellow spots and trash content along with the means of L*, a* and b*, cotton samples can be better described than ever.

The agreement between the cotton classer and the HVI calorimeter is about 70 %. This is not surprising because only mean values of Rd and +b are used in classifying samples into white, light spotted, spotted, tinged and yellow stained color grade. Using additional measurements and a well trained, advanced classifier, the agreement can be improved significantly.

Acknowledgements

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Table 1. Color results for Color Check Samples.

	Rd	+b	L*	a*	b*
C1	79.9	9.4	96.694	0.255	11.732
C2	77.6	8.6	95.476	0.142	11.231
C3	74.9	7.3	94.058	-0.026	9.947
C4	71.3	6.6	92.245	-0.109	9.062
C5	63.8	5.8	87.852	0.171	7.904
C6	58.9	6.3	85.875	0.446	8.63
C7	69.2	14.4	89.367	2.43	18.01
C8	68.1	10.9	89.631	0.716	13.851
C9	63.1	10.9	87.098	1.028	13.451
C10	57.3	10	83.961	0.913	11.94
C11	65.6	13.6	87.907	1.843	16.781
C12	59.2	12.7	84.481	1.974	15.618

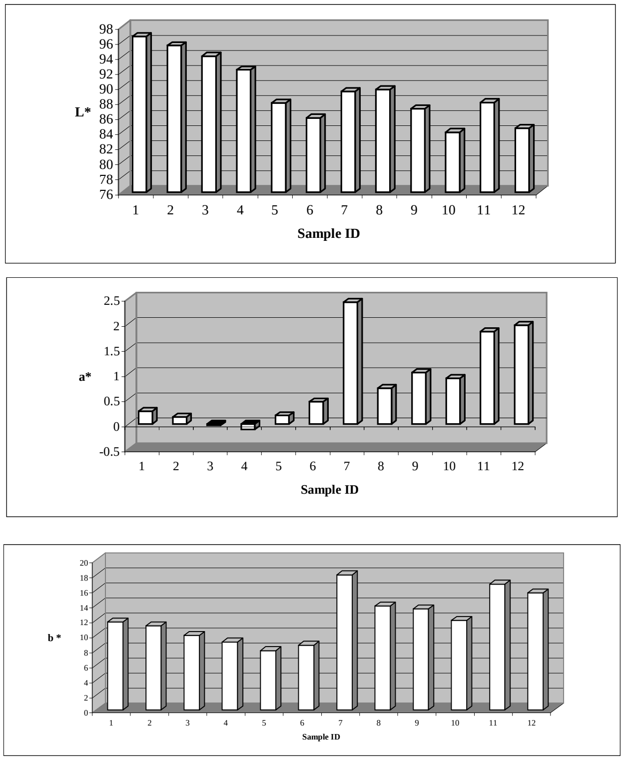


Figure 1. (a) L* for 12 samples, (b) a* for 12 samples, (c) b* for 12 samples.

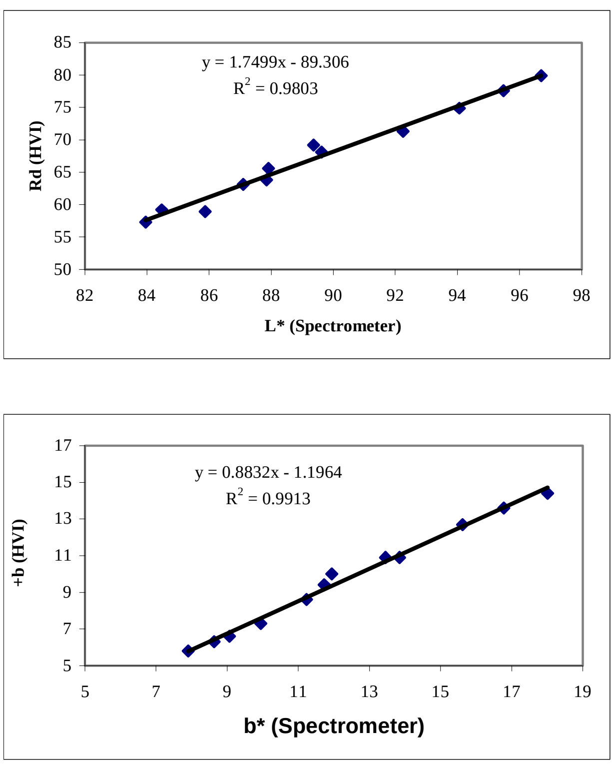


Figure 2. Correlation between HVI and Spectrometer.

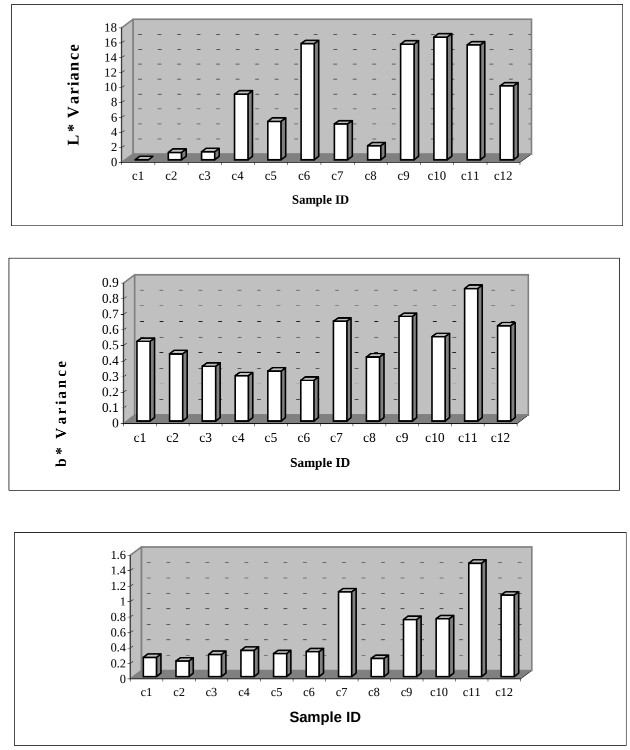


Figure 3. Variance of L*, a* and b* for 12 samples.

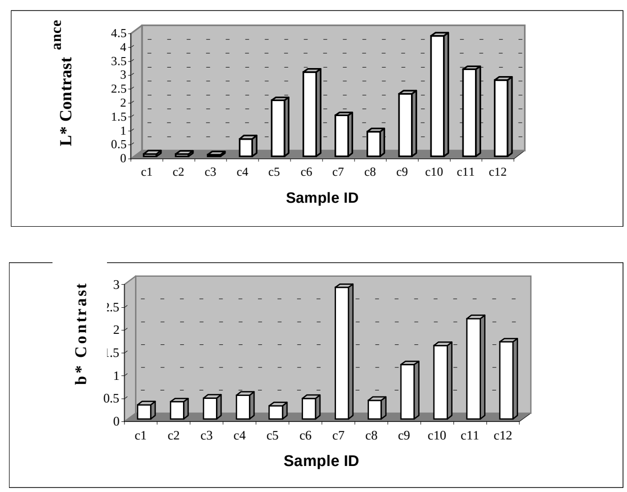
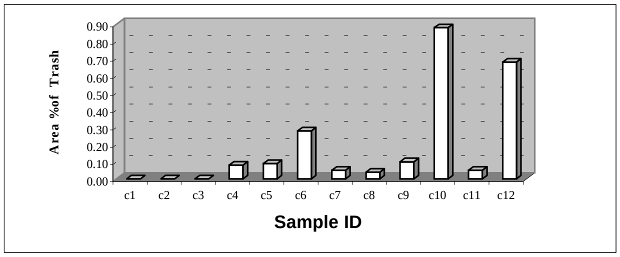


Figure 4. Contrast of L* and b* for 12 samples.



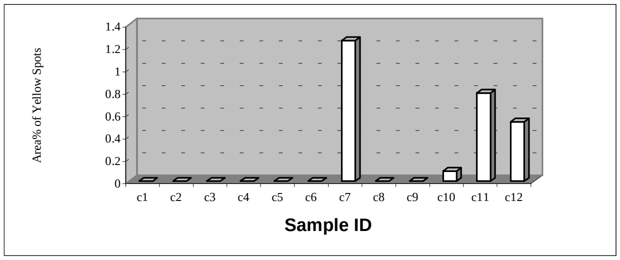


Figure 5. Percent Area of Yellow Spots and Trash for 12 samples.