CHROMATIC IMAGE ANALYSIS FOR COTTON TRASH AND COLOR MEASUREMENTS

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Abstract

The U.S. cotton classification system has been undergoing significant change, moving from human classing to the utilization of precise instruments. Along with this trend, the current research is an effort to develop a new computer vision system to measure detailed trash and color attributes of raw cotton. The system primarily consists of a color CCD camera, xenon flash light, and customized software. In this paper, we will introduce a new trash and spot identification method, multi-dimension thresholding, and the methods for characterizing size, spatial density, shape, and color of trash and spots present in cotton samples. The trash and color measurements of twelve cotton samples, including statistical data and distribution curves, will be reported. The results obtained from this system will be compared with those obtained from other instruments such as Spinlab and Motion Control HVI machines and Minolta Chroma Meter CR-210. The influences of trash and spots on cotton color values will be investigated.

Introduction

Cotton trash and color are the determinants in judging the spinning quality and hence the market value of cotton in the current cotton grading system. Trash in cotton refers to non-lint particles such as leaf, seedcoat, bark, grass, dust and other foreign matters. The presence of trash degrades yarn evenness, yarn strength and fabric appearance and causes problems in textile processing. The methods that are used for assessing trash content fall into two basic categories: gravimetric and geometric. Gravimetric methods evaluate trash content by trash weight, while the geometric methods estimate the area covered by trash particles. The typical gravimetric devices are the Shirley Analyzer (mechanical separation of foreign matter from fiber), the MicroDust and Trash Analyzer (aero-mechanical separation). The AFIS-T (Advanced Fiber Information System, Trash module) uses the aero-mechanical technique to separate trash particles into fractions, and an electro-optical sensor to measure particle size in each fraction. The USDA cotton universal standards provide a geometric method for grading the leaf content of U.S. upland cotton [12]. The seven leaf grades are represented by physical standards. Currently, the trash grading of the majority of U.S. cotton is determined by the trashmeters of high-volume instruments, commonly referred to as HVI. The HVI trashmeter is a typical geometric instrument that uses the image processing techniques to measure overall trash areas in the sample. Although the trashmeter is a very efficient trash measuring instrument and the result is correlated to the classers' grades [2, 13], the image analysis techniques used in the trashmeter limit its data to the count and the percent area of trash particles. It lacks the ability to provide information about detailed particle size distribution and trash category, which are extremely useful for process optimization and prediction of cleaning behavior during processing [13]. Since the trashmeter employs a black and white video camera and a simple image thresholding technique [9, 10], trash mis-identification, such as surface shadows and dark spotted areas, cannot be effectively avoided.

Normally, cotton has a bright, white color. Continued exposure to weathering and the action of micro-organisms may cause white cotton to lose its brightness. If frost or drought stops cotton growth prematurely, cotton may have a yellow color that varies in depth. The action of insects, fungi, and soil stains may result in cotton discoloration [2, 12]. Locally yellowed areas in a cotton sample are regarded as spots. Abnormal color indicates a deterioration in quality, because the lint color is related to processing performance and yarn quality [2, 4]. In the USDA universal standards, color grades are divided into five groups: white, light spotted, spotted, tinged, and yellow stained, and each group has several divisions: good middling, strict middling, middling, etc. [2, 12]. Cotton color grades decided by this subjective method depend on the assessment of the overall color of the sample and the presence of spots. The HVI colorimeter can accurately measure color grayness (R_d) and yellowness ($+b$), and the data are correlated with the visual grades [1]. The colorimeter is able to measure only the average color over a small surface area of the sample, and unable to tell whether a sample is spotted or uniform in color, or whether the measured area includes trash particles or not. Therefore, spotted areas and trash particles may distort the true lint color attributes.

A research project has been conducted to expand the functions of the HVI trashmeters and colorimeters by using more advanced imaging devices and more effective image-processing techniques. The emphases of this newly-developed cotton trash and color measurement system (CTCM) were on incorporating trash and color measurement into one video image system, and on utilizing reliable trash and spot identification algorithms. This paper explains a new thresholding method that extracts trash, spot and shadow from a cotton image, and the methods for characterizing size, shape, color and density of trash particles. A trial test was done to compare the results obtained from this system with those obtained from other instruments such as Spinlab (SPL) and Motion Control (MCI) HVI machines, Minolta Chroma Meter CR-210, and

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to analyze the influences of trash and spotted areas on the overall color measurement of the samples.

Methods

System

To make the system able to measure both trash content and color attributes, the previous black/white camera was replaced with a 3-chip color CCD camera (JVC KY-F55B). This camera has a high resolution and convenient ways to adjust white balance and other settings. The light source used in the HVI trashmeter is two incandescent lamps on two sides with 45 degrees illumination [10, 11]. One of the disadvantages of this lighting is that it is unable to provide a uniform illumination over the entire viewing area (approximately 6.35x7.94 cm^2). A xenon flashlamp (Vivitar Electronic Flash 1900) was used in the system because it can uniformly illuminate a relatively large area with high-intensity, short-duration pulses. It was found that the overall variation in intensity in a grabbed image of a white paper over the same viewing area is 2.3%. A specially designed circuit was added to the Vivitar flasher to obtain a steady flashing intensity each time the camera captures the image, and therefore the repeatability of color measurement can be ensured. The overall color difference between two measurements done at one-hour interval can be limited to 1%. The computer triggers the flasher when an image is being grabbed. The schematic set-up of this computer vision system is presented in Figure 1. In this research, the image-capturing box of a used HVI trashmeter was modified to mount the new camera and flash. Cotton samples are pressed flat against the window glass, and a rectangular area of the sample (8.47x6.35 cm^2) is imaged. The frame grabber is a 24-bit board that was plugged into the computer, and permits a bitmap image to possess up to 16.8 million colors. The image size is 640x480 pixels, yielding a resolution of 0.132 mm/pixel. The actual imaged area is adjustable, but the maximum area is confined by the window of the trashmeter box. A software package, written in Microsoft C/C++, controls the flasher and camera, and extracts various trash and color information from the sample.

Identification of Irregular Regions

A raw cotton sample usually contains trash particles and spots. Trash particles appear darker, and spots look more yellow than cotton lint. Unevenly-spread fibers on the surface of the compressed sample may cause shadows (dark, grayish areas). These chromatic areas (trash, spots and shadows) in the color image of the sample are called irregular regions. Although most shadows can be eliminated in the image by applying an appropriate compressing pressure and lighting sources [10,11], it is not uncommon to see shadows in an image. The HVI trashmeter tends to distinguish these regions in the image by selecting a brightness threshold based on the average intensity of the image. This threshold-determining method makes the region identification sensitive to the image illumination condition. The sizes of detected areas vary with the threshold. For example, image *a* in Figure 2 shows a cotton sample which contains trash, spots and shadows. If the threshold selected is too low, the spots and shadows may be falsely identified as trash particles, and the identified areas will appear larger than their visual perceptions (image *b* in Figure 2). Conversely, if the selected threshold is too high, relatively bright trash particles may not be identified, and trash size will appear smaller than their actual size (image *c* in Figure 2). The shortcoming of this thresholding technique is due to the fact that the image captured is monochrome, and the gray scale information (lightness) is insufficient for differentiating these features.

The color imaging system developed in this research permits image features to be identified not only by lightness, but also by other color attributes. Colors in an image are expressed in the NTSC *RGB* color system. Hence, three color primaries, red, green and blue (*RGB*), can be obtained for each pixel directly from the image. While *RGB* values represent how the color detector works and how the color data are stored initially, they do not directly correspond to how an observer recognizes or reacts to color. A color coordinate system based on hue, saturation, and lightness is more consistent with visual perceptions. This is the CIE L^*C^*h system, where L^*C^* and h are lightness, chroma and hue, respectively (the conversion from *RGB* to L^*C^*h will be given in the next section). Figures 3 shows the typical L^*C^*h distributions of the cotton sample shown in image *a* of Figure 2. The peaks of these three curves correspond to the L^*C^*h values of the white cotton lint. Typically, the lint has a brightness around 90, a chroma around 9, and a hue angle 85^o (yellow regions in a color wheel).

The typical L^*C^*h values of trash particles, spotted and shadowed areas can be obtained by manually selecting a number of these features from various images. Their L^*C^*h distributions are presented in Figure 4 to show the variations (the dash lines indicate the values of the cotton lint). In general, these areas are darker but more chromatic than the cotton lint. While the hue angles of spots and shadows are close to those of white lint, trash particles show significantly different hue angles (in an orange-yellow range). Although one threshold in either lightness or chroma is inadequate to discern these features from white lint, using sets of thresholds in both dimensions and combining the two criteria with a logical 'AND' can achieve this goal more effectively. That is, if a pixel satisfies:

$$L^* < L_0^*; \quad \text{and} \quad C^* > C_0^*$$

the pixel will be assigned to the irregular regions. Here, $\mathbf{L^*_0}$ and $\mathbf{C^*_0}$ are a set of the threshold. Image *a* in Figure 5 shows identified trash, spots, and shadows in the sample (image *a* in Figure 2). Note that isolated, small dots are removed from the image. When the color attributes of the sample are calculated, these areas can be excluded from the image so that only the color of the cotton lint is considered. Based on this irregular-region map, trash, spots and shadows can be further separated. From Figure 4, it can be found that spots have higher C^* and shadows have lower C^* than trash particles, and both groups have higher $L^*$and h than trash particles. Figure 6 illustrates the logic of this multi-dimension thresholding algorithm. $\mathbf{L^*_1}$, $\mathbf{C^*_1}$, h_1 and $\mathbf{C^*_2}$ are a set of threshold levels that are determined from the averages and standard deviations of L^*C^*h values in these regions. Images *b*, *c* and *d* in Figure 5 are the maps of separated spots, shadows and trash particles.

Characterization of Irregular Regions

After trash and spots are identified, their size, spatial density, shape, and color characteristics can be calculated. The measurements quantify trash and spot levels of the sample, and are also the important information for trash classification and cotton classing.

The area of an identified region refers to as the number of black pixels clustering together (Figure 5). The computer counts black pixels belonging to the region, and then converts the pixels to a size in mm^2. After all the areas are counted, the following size descriptors can be calculated and reported.

Size Statistics: the mean, standard deviation, maximum and minimum of the measured sizes.

Area Fraction: ratio of the total size of trash particles or spotted areas to the image size. This can be used as an overall measure of trash content or spot level.

Size Distribution: a curve that shows the frequency of each size over a
typical range. When an adequate number of areas are counted, the distribution curve reveals the dispersion of the measured sizes.

The spatial density of trash particles in a cotton sample is another indicator of trash content. It is particularly valid when trash particles are small and uniform. Physically, the spatial density D means the number of particles per unit area. Since particles are not always randomly distributed in the image, it is necessary to use the nearest-distance technique to estimate D [7]. The nearest-distance r_i is a distance between the mass centers [5] of two closest particles. If n particles are found, D can be calculated as follows [7]:

$$D = \frac{2n}{\pi \sum (r_i^2)}$$

Statistically, common trash particles, such as leaf, bark, and seedcoat, seem to have different shapes. Therefore, the shape information provides an important cue for trash classification. The shape descriptor *Roundness* (R) is chosen for trash characterization. R is defined as the ratio of a particle area to the area of a circle whose perimeter is equal to that of the particle. R measures the similarity of a given shape to a circle. Since small particles are more likely to appear circular due to digitization, only particles larger than a given size are included in the data.

Colors of trash and spotted areas can influence the color data of the sample if they are included during the measuring. It is important to know, quantitatively, the color attributes of these areas so that the color of cotton lint can be determined more precisely. Furthermore, color may be the supplemental information for distinguishing trash categories (this will be covered in another study). An HVI colorimeter measures the average R_d and $+b$ values over a small area, in which trash particles and spots may be present. It is unable to separate trash from cotton lint and to provide distributions R_d and $+b$. The CTCM can automatically locate individual areas of trash and spots, and calculate the color attributes both inside and outside these areas. Hence, the influences of these areas on the sample's color can be assessed. From the initial the *RGB* data, the following color coordinate systems can be converted in the system [1, 3, 5]:

XYZ tristimulus system:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.607 & 0.174 & 0.201 \\ 0.299 & 0.586 & 0.114 \\ 0.000 & 0.066 & 1.118 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

CIE *L*a*b* color system*:

$L^* = 116(Y/Y_0)^{1/3} - 16$

$a^* = 500[(X/X_0)^{1/3} - (Y/Y_0)^{1/3}]$

$b^* = 200[(Y/Y_0)^{1/3} - (Z/Z_0)^{1/3}]$

where L^* is the lightness, a^* is the red-green coordinate and b^* is the yellow-blue coordinate. The X_0, Y_0 and Z_0 are the tristimulus values of a perfect reflecting diffuser.

CIE *L*C*h color system*: L^* is unchanged.

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$
$$h = \tan^{-1}(b^* / a^*)$$

$R_d$ab color system:

$$R_d = 100(Y / Y_0)$$
$$a = 175\, f_y (1.02X / X_0 - Y / Y_0)$$
$$b = 70\, f_y (Y / Y_0 - 0.847Z / Z_0)$$

where: $f_y = 0.51(21+20Y/Y_0)/(1+20Y/Y_0)$ $R_d ab$ is a system similar to $L^*a^*b^*$ and is most commonly used for the cotton color description. The cotton colorimeters often ignore *a* coordinate, outputting only R_d (lightness or reflectance) and $+b$ (yellowness).

Experiment And Discussions

Twelve cotton samples (S1~S12) with various trash contents were used as the experimental materials. For each sample, five images were captured at different locations of the sample, and the results from the five images were combined for the final report. The samples were also tested by Spinlab and Motion Control HVI machines and Minolta Chroma Meter CR-210, and therefore some comparisons could be made in the research.

Trash Measurement

Table I gives trash measurements including various size, density, shape and color information. S9 has the largest size (2.09 mm2); S1 has the highest trash content and density; S2 is the cleanest among these samples. According to a known relationship between classers' leaf grades and trashmeter readings [1], the leaf grades of these samples can be decided based on the measurements of trash contents. S2 falls into grade 1; S3, S4, S7, S8 and S10 are in grades 4~5; S6, S11 and S12 are in 5~6; S5 and S9 are in 6~7; S1 is above grade 7. The trash content measurements are also directly compared with those obtained from the SPL and MCI HVIs (Figure 7). Overall, the results from the three machines are very consistent. The differences may arise from different trash segmentation algorithms and calibration methods, and different portions of a sample used in the three systems. It seems that there is a systematic difference between SPL and MCI trashmeters.

Figure 8 shows the size distribution of S1. The high concentration in the small size range (around 1 mm2) results from pepper leaves and small seedcoat fragments predominantly present in the sample. A relatively large frequency around 5mm2 corresponds to large leaves and barks. The trash sizes which are smaller than 0.5 mm2 are not displayed in the distribution because they are in the range of dust according to the recommendation of the International Textile Machinery Federation [13]. The size distribution may be useful in determining the process parameters of ginning, opening, cleaning, carding and combing.

The average roundness of trash particles in these 12 samples disperses in a wide range, from 0.36 (S9) to 0.69 (S4). To some extent, the shape of a particle reflects its trash category (leaf, bark, seedcoat, etc.), and thus the roundness can be used for trash classification. For example, seedcoat fragments usually have relative large roundness values, while barks have small roundness values. Table I also presents the color measurements of trash particles in the samples. The color attributes of trash particles are other useful information for identifying trash categories, because a color is more or less related to a certain type of trash. Normally, trash particles have much higher *a* values than cotton lint. Combined information of size, shape, and color acquired from this system may offer a base for a new approach to classify trash particles.

Color Measurement

The system provides a comprehensive functions for measuring cotton colors and distributions in various color coordinate systems. The measured R_d and $+b$ results are compared to those obtained from the three colorimeters, SPL, MCI and Minolta Chroma Meter CR-210 (Figure 9). The results exhibit a high consistency between the systems, although the R_d and $+b$ readings of the Minolta CR-210 are systematically lower than the corresponding readings of the other colorimeters. This is because any difference in light source, color sensor and set-up geometry may contribute to the differences in the results that colorimeters output. This figure indicates that the CTCM system has been adjusted to generate R_d and $+b$ values very similar to those of SPL and MCI colorimeters.

The system is also able to yield the distributions of the color attributes since it measures color of every pixel in a relatively large area. Figure 10 shows the $R_d ab$ distributions of S1, indicating the dispersions of the color measurements in the sample. The red-green attribute *a* concentrates in a range from -5 to 5 with larger distributions being in the positive range. A negative *a* indicates a green constituent in the sample. Usually, the average *a* of a cotton sample falls in the range of 1~2, and the average *b* in the range of 6~10. Because of a relatively small portion of *a*, only R_d and $+b$ are taken into account in the current cotton color measuring systems. In other words, the cotton redness information is ignored. Figure 11 shows the (*a*,*b*) data of the twelve samples in a color circle, where the radius *C* stands for chroma, the angle *h* for hue, and the center for the gray axis. *C* ($C=\sqrt{\mathbf{a}^2+\mathbf{b}^2}$) measures the distance of a color away from the grayness. In the tested samples, the *a* component takes 10% ~20% of *C*. For a tinged or yellow stained sample, the *a* content is expected to be even higher. When this percentage is not negligible, *C* is a more reasonable factor that reflects the chromaticity of the cotton than $+b$.

Influence of Trash Particles on Cotton Color Measurement

The cotton color measured by SPL, MCI and Minolta colorimeters is the average color of the viewed window. Since the CTCM can separate trash particles from cotton lint during the color measurement, it is possible to analyze the color differences between the pure lint (fiber) and the contaminated sample. If ΔE denotes the relative difference in one color attribute, R_d, *a* or *b*, ΔE can be calculated as follows:

$$\mathbf{\Delta E + (C_f\text{-}C_s)/C_s{*}100\%}$$

where *Cf* is a color attribute, R_d, *a* or *b*, of the cotton fiber, *Cs* is the same color attribute of the sample (both trash and fiber). A positive $\Delta E(C_f > C_s)$ indicates a color reduction in the sample. Table II summarizes the ΔE in R_d, *a* or *b* of all the samples. Since the $\Delta E(R_d)$ values of all the samples are positive, the samples should have a reduction in R_d when trash particles are included. But trash causes both negative and positive ΔEs in a and b, meaning that changes in redness or yellowness do not show a definite trend with trash. This is because different types of trash will add different chromatic elements to the samples, although they are all darker than cotton fibers. In most cases, ΔEs in b are the smallest, whereas ΔEs in a are the largest. This means that trash affects the a data most. Any change in a, however, is overlooked by the HVI colorimeters. The total color difference T caused by trash in a sample can be calculated from the magnitudes of the three separate differences:

$$T = \sqrt{[\Delta E(R_d)]^2 + [\Delta E(a)]^2 + [\Delta E(b)]^2}$$

Among these samples, T varies from 0.63% (S2) to 5.36% (S9). T can be considered as the trash's influences on cotton color measurements, and is a measure for the difference in color grades that may exist between human classers and the HVI colorimeters.

Figure 12 shows the ΔE (R_d)data in relation to the trash contents, and the regression line. Overall, the two variables have an upward linear relationship (r^2= 0.91). This relationship provides a way to predict the possible cotton reflectance reduction brought out by trash when the trash content of the sample is known. Since the HVI colorimeter cannot exclude trash particles present in the tested area, a R_d correction may be necessary to be made based on the prediction of R_d reduction. This study does not find a certain relationship between $\Delta E(b)$ and the trash content, because the color change in b is more related to the trash categories than to the trash content (amount). Therefore, the $\Delta E(b)$ data were plotted against trash b in Figure 13. The regression line of the data has a downward trend, which crosses zero around b=8.7. When the trash's b is lower than the fiber's b, $\Delta E(b)$ will be positive, indicating a reduction in the sample's b. A negative $\Delta E(b)$ implies an increase in the sample's b. Note that the varying range of $\Delta E(b)$ is very small (-1%~1%). Trash is not a primary factor that influences the b readings of the cotton samples.

Influence of Spots on Cotton Color Measurement

As mentioned previously, cotton may become discolored or spotted by insects, fungi, or other sources. Current cotton colorimeters cannot give information about whether the cotton is spotted or not. It was reported that the average color of light spotted cottons is nearly the same as the average color of the white grade cottons [4]. This is because light spotted cottons have similar background colors as white grade cottons. Therefore, it would be an advantage that spots in cotton can be identified and measured. With the CTCM system, individual spotted areas can be located, the area and color of the spotted areas can be measured, and the fraction of the spotted areas can be calculated accordingly. Table III gives the measured results of spotted areas in the samples.

Spotted areas have a much larger average size than trash particles existing in the same sample. Spots account for 0.27%~1.46% of the measured areas in these samples (spot content). In general, spots and trash particles have comparable R_d and a values but quite different b values. Spots have much higher b values than trash particles, and influence the colors of the samples differently. Figure 14 shows the changes in the $\Delta E(R_d)$ with the spot content. Generally, the higher the spot content, the more R_d reduction in the samples. A lower degree of correlation between these two variables indicates less influence of spots on the change in R_d than trash particles. Figure 15 shows the correlation of $\Delta E(b)$ with the spot b. All the samples show negative $\Delta E(b)$, meaning spots cause the increase in the samples' b. A further study will be directed to classify the identified spots, and in turn, help to understand the cause of the spots. The spot information obtained from the CTCM will make cotton color measurements more meaningful, when compared to classers' grades.

Conclusions

The newly developed system uses the same hardware to measure both trash content and color attributes of raw cotton. The xenon flasher used in the system can provide a uniform and stable light source to illuminate a sample area larger than the one in the HVI trashmeters. The multi-dimension thresholding method enables the system to effectively identify trash particles, shadows and spots, and therefore these regions can be excluded when the color of the sample is measured. The comprehensive trash measurements, including count, size, spatial density, shape and color, can be provided for trash characterization, facilitating a further study for classifying trash particles. In addition to $R_d ab$, cotton color can be measured in other color coordinate systems such as CIE $L^*a^*b^*$ and L^*C^*h, and the information about color distributions and variations is available as well. The system is also a tool to analyze the influences of trash particles and spots on cotton color measurements. A trial test showed that the trash and color measurements obtained from this system are highly consistent with those from the current HVI trashmeter and colorimeter. It also revealed that a component (redness) takes 10%~20% of cotton chroma, and trash can result in a color difference up to 5.36%.

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Table I Trash Measurements

	Area (mm2)	Content (%)	Density (1/cm2)	*R*	R_d	*a*	*b*
S1	1.43	1.89	1.40	0.41	43.50	4.07	9.77
S2	1.16	0.08	0.18	0.57	54.83	5.79	9.70
S3	1.10	0.39	0.38	0.66	52.77	4.45	9.10
S4	0.51	0.34	0.78	0.69	50.72	4.83	7.97
S5	0.93	0.96	1.16	0.58	44.31	4.73	6.50
S6	1.75	0.81	0.50	0.40	48.48	4.81	8.85
S7	1.23	0.34	0.26	0.46	51.72	4.15	7.43
S8	1.22	0.38	0.25	0.42	47.04	4.03	8.60
S9	2.09	1.03	0.50	0.36	51.05	4.07	9.27
S10	0.94	0.51	0.55	0.54	49.13	4.69	7.05
S11	1.43	0.78	0.60	0.51	51.02	5.61	11.3
S12	1.35	0.83	0.68	0.48	52.89	4.98	9.86

Table II Color Differences Caused by Trash

	Sample Color			ΔE (%)			
	R_d	*a*	*b*	R_d	*a*	*b*	*T*
S1	60.30	2.03	8.94	1.22	-2.52	-0.39	2.83
S2	72.95	1.74	8.65	0.52	-0.35	0.08	0.63
S3	74.56	1.75	9.24	0.26	-2.08	-0.02	2.10
S4	69.24	1.77	9.36	0.23	-1.24	0.10	1.27
S5	66.42	1.61	8.43	0.76	-3.91	0.65	4.04
S6	70.12	1.91	9.47	0.57	-3.43	0.11	3.48
S7	71.86	1.25	7.21	0.19	-0.37	0.70	0.81
S8	63.92	1.86	8.72	0.14	-0.88	-0.02	0.89
S9	67.80	1.92	8.79	0.51	-5.32	-0.34	5.36
S10	70.85	1.82	8.70	0.32	-5.03	0.09	5.03
S11	70.18	1.58	8.49	0.46	-4.02	-0.63	4.05
S12	72.74	1.55	8.68	0.35	-3.93	-0.27	3.95

Table III Measurements of Spotted Areas

	Area (mm2)	Content (%)	R_d	*a*	*b*
S1	5.10	1.01	46.77	4.38	13.70
S2	2.85	0.27	53.41	3.80	14.17
S3	4.73	0.41	53.43	3.64	14.33
S4	4.20	0.37	52.40	3.53	13.68
S5	4.55	0.64	51.55	3.80	14.95
S6	4.77	1.46	53.77	3.42	13.44
S7	5.47	0.70	53.52	3.96	14.61
S8	4.68	0.36	53.71	4.06	13.85
S9	8.29	0.76	52.51	3.76	13.90
S10	5.14	0.77	52.90	3.80	14.14
S11	3.84	0.55	53.93	2.69	13.07
S12	3.53	0.79	53.66	3.29	13.38

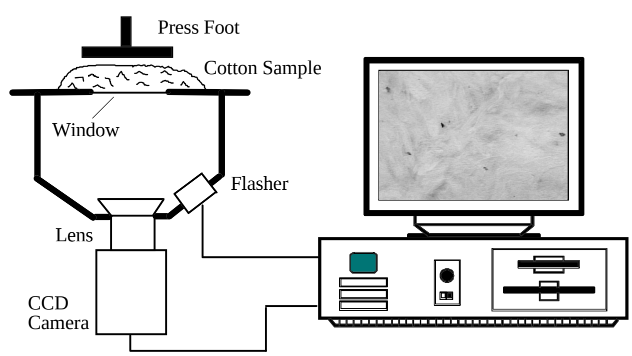

Figure 1 Schematic Set-up of the System

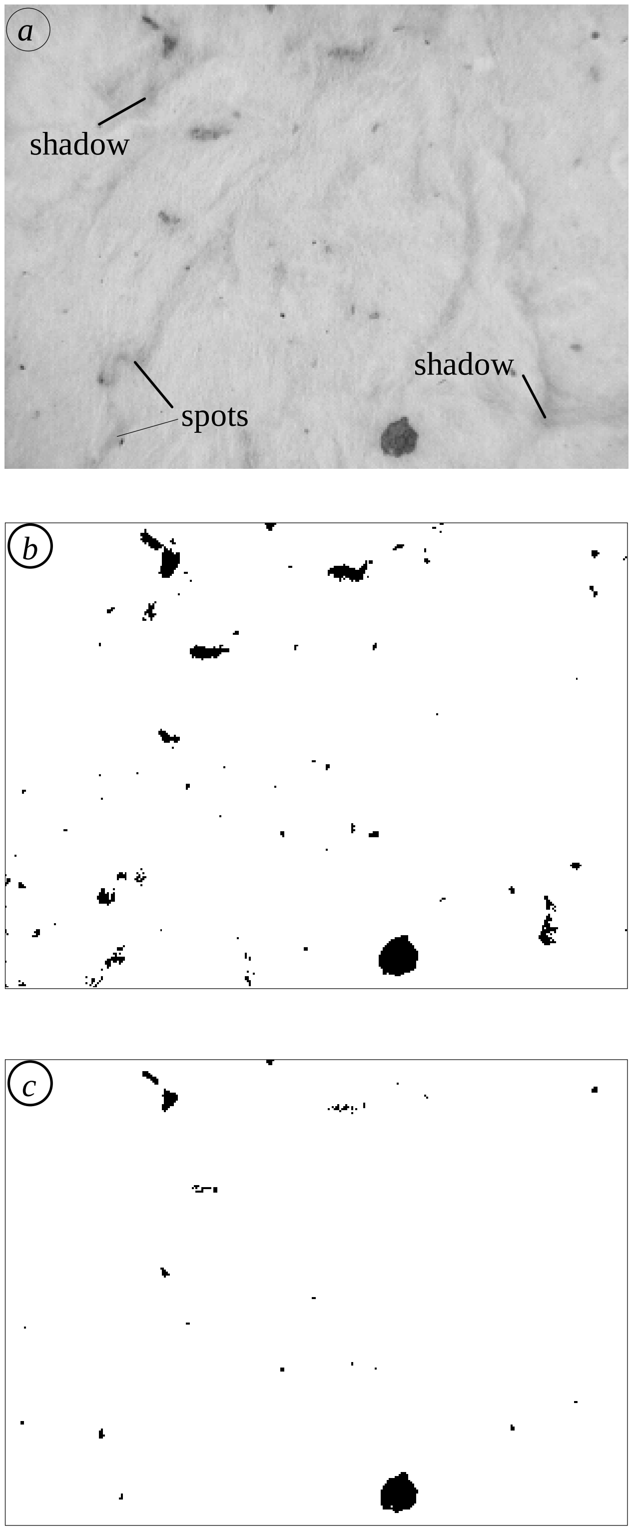

Figure 2 Lightness Thresholding
a. raw image, *b*. overestimated, *c*. underestimated

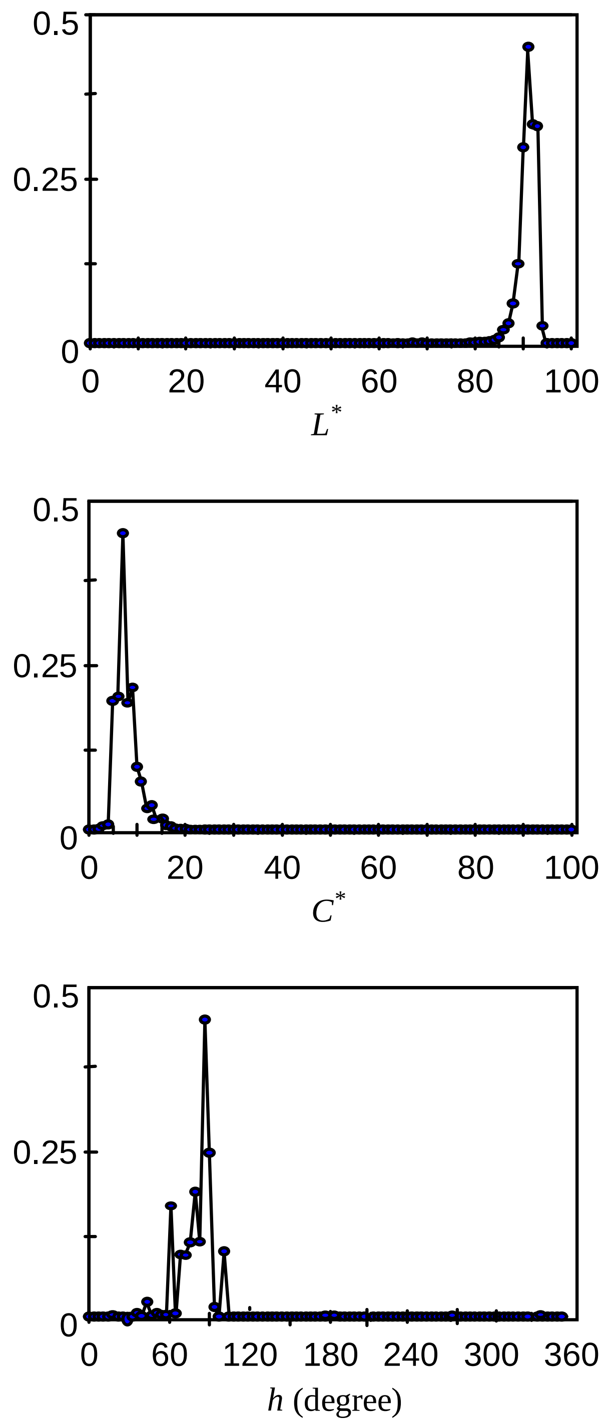

Figure 3 L^*C^*h Distributions of Cotton Sample

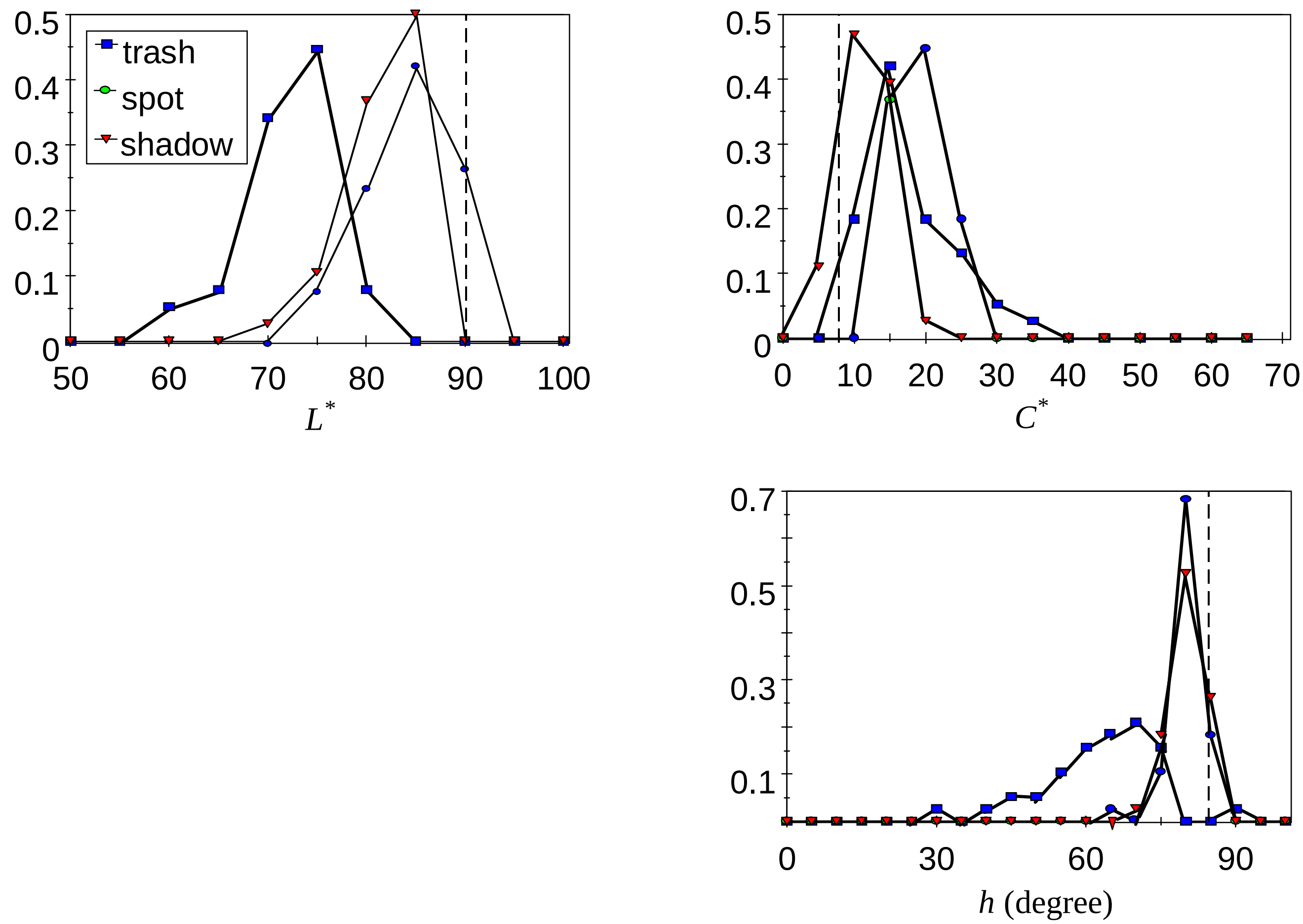

Figure 4 *L*C*h* Distributions of Trash, Spots and Shadows

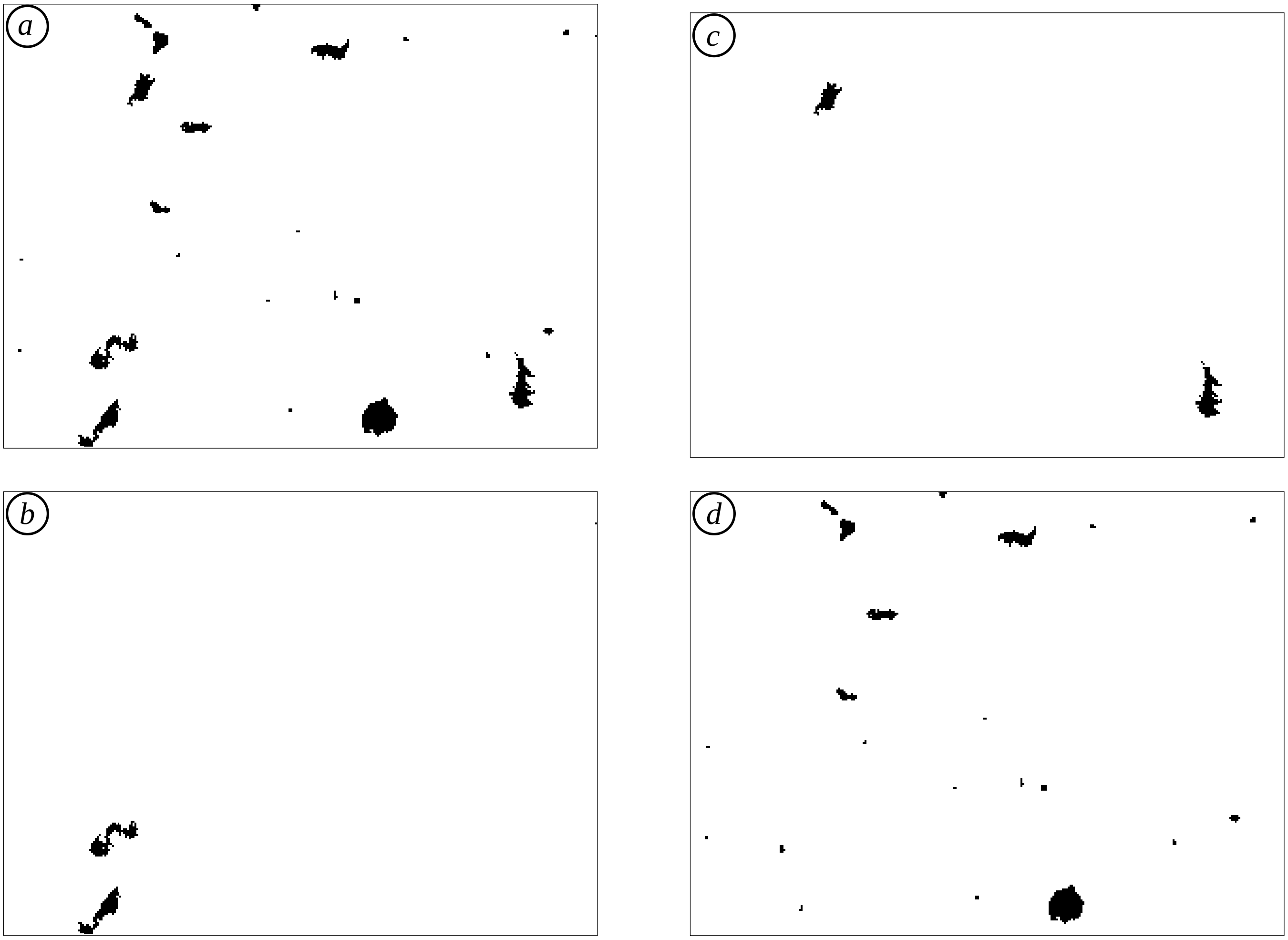

Figure 5 Identified Irregular Regions *a*. All, *b*. Spots, *c*. shadows, *d*. Trash Particles

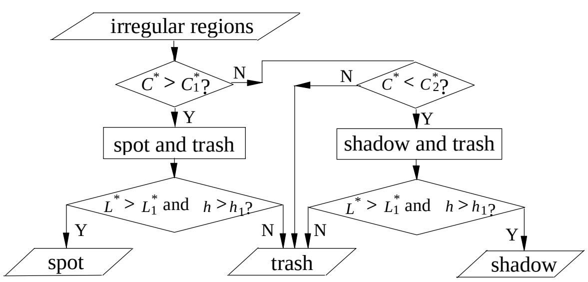

Figure 6 Multi-Dimension Thresholding

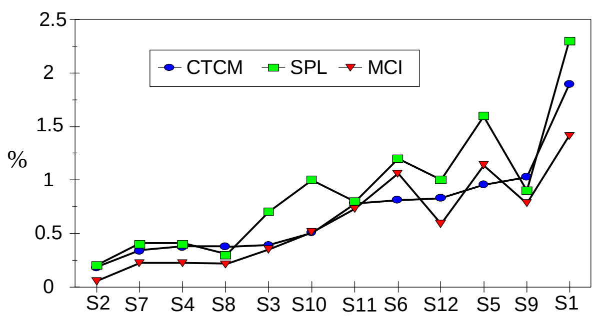

Figure 7 Comparison of Trash Contents

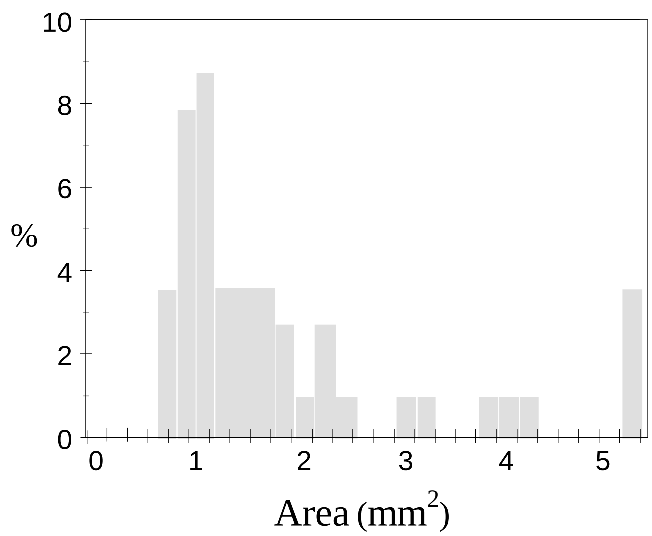

Figure 8 Size Distribution of S1

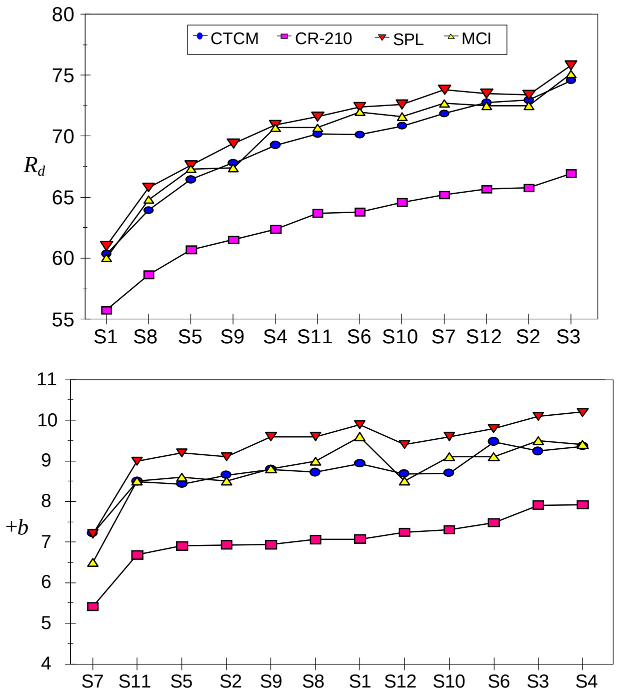

Figure 9 R_d and $+b$ Comparisons of the Samples

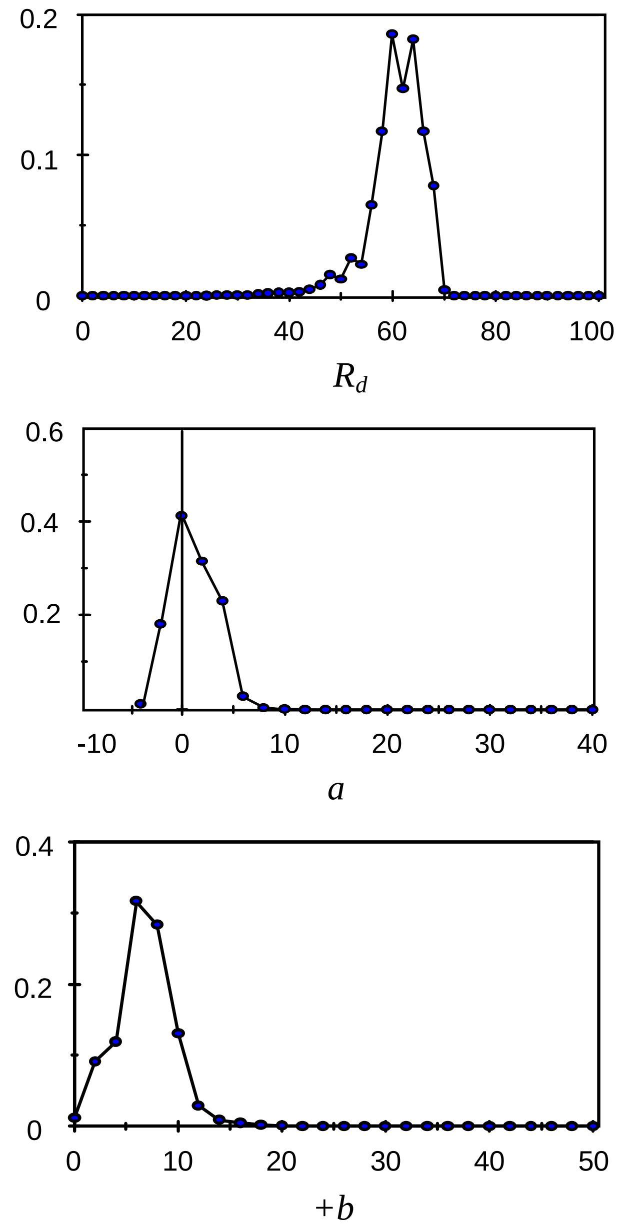

Figure 10 $R_d ab$ Distributions of S1

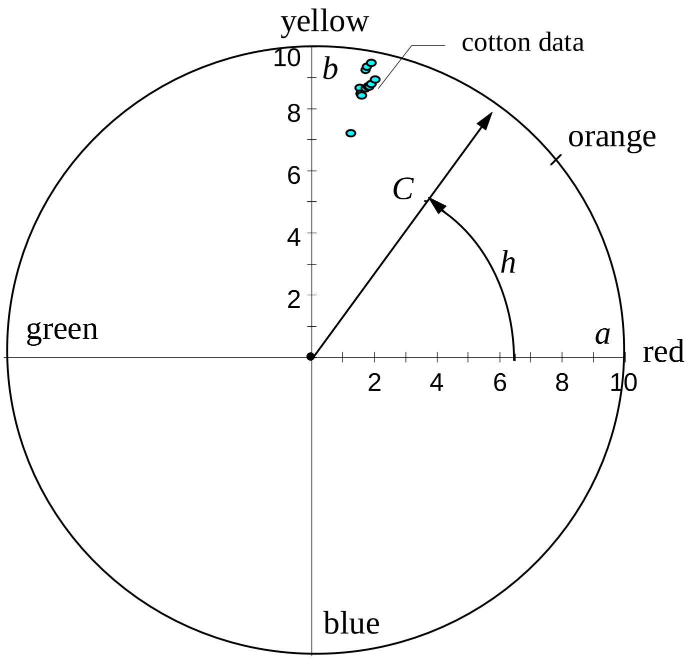

Figure 11 Cotton *a*-*b* Data in a Color Circle

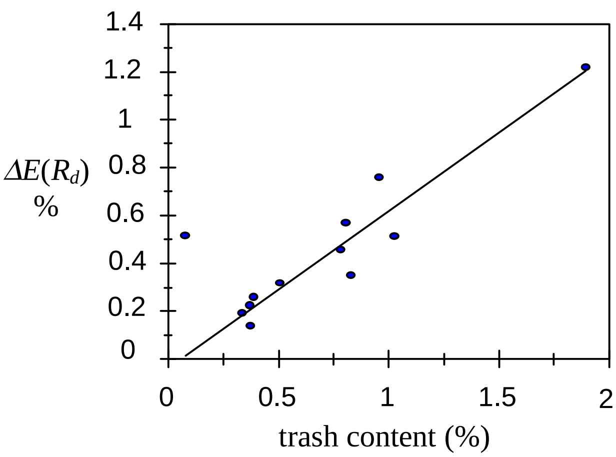

Figure 12 Relationship between $\Delta E(R_d)$ and Trash Content

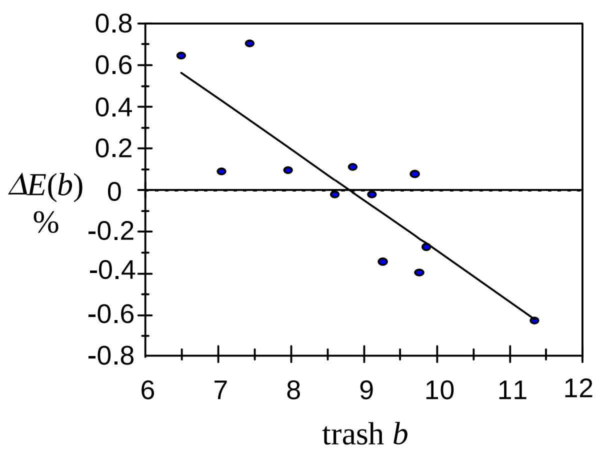

Figure 13 Relationship between $\Delta E(b)$ and Trash *b*

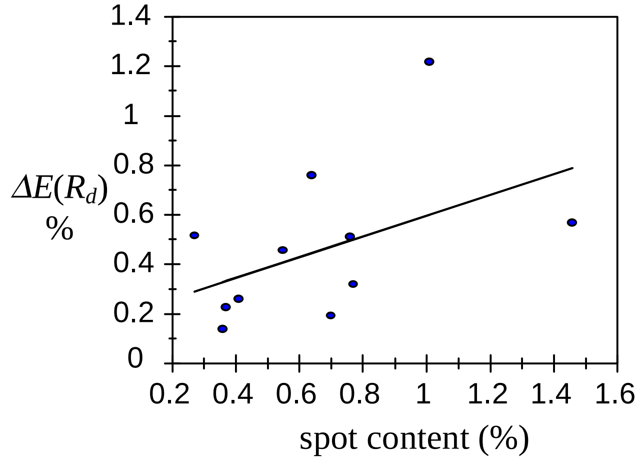

Figure 14 Relationship between $\Delta E(R_d)$ and Spot Content

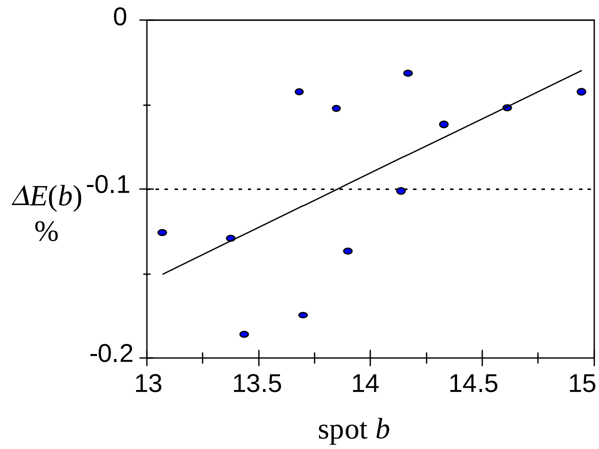

Figure 15 Relationship between $\Delta E(b)$ and Spot *b*