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Objective Measurement of Level and Union Shades in Wool and Wool/Cotton Textiles

ABSTRACT

A method of determining the level and union shades of fabric by digital image analysis has been developed. Digitizing an image involves computer-based systems, peripherals, and software configured to access, process and display image data. These data can be video-displayed and computer-manipulated through various transformations for statistical treatments and mathematical relationships. The distribution of the number of pixels in a digitized image at a particular gray scale as a function of the gray scale can be portrayed as a histogram.

The histogram features of dyed textiles were identified and used for objective measurements of level dyeings in 100% wool fabric and for union dyeings in 50/50 wool/cotton union fabrics. These dyed fabrics were pretreated with a durable press resin and quaternary amine compound by a pad/dry/cure process. They were subsequently dyed with C.I. Acid Red 114, C.I. Direct Red 79, C.I. Reactive Red 2 and C.I. Reactive Blue 19 in efficient, salt-free dyeing processes.

Levelness values were developed from standard deviations of the gray scale means of individual histograms of the dyed fabrics. Union shades were determined by analyzing the shapes of the histograms where high, narrow, symmetrical shapes suggested union shades. Low, broad and skewed shapes suggested nonunion shades. Mathematical and statistical treatments of histogram data led to establishing thresholds and relative comparisons of dyed fabrics for union and level shades.

Nonuniform color is a serious and prevalent problem in the wet processing of textiles. Color nonuniformity is associated with the inability of a dye to level or migrate in the dyebath for uniform dye distribution within a dyed fabric. The term *union* refers to a dye that uniformly dyes a fabric blend, such as wool and cotton. Blends can be intimate when in the form of yarn, or union when the blend comprises warpwise (i.e., wool) and weftwise (i.e., cotton) interlacing yarns.

Color nonuniformity is so common that regular protocols involving the addition of a leveler under strict time, temperature and pH conditions have been developed to reverse it. The persistent demand for shade uniformity has led to a proliferation of reports on the theory and application of proprietary levelers of various amphoteric, anionic and cationic compositions.[1,2]

Conventional approaches for examining levelness have been based on detailed investigations of the dyebath, dye affinity, liquor ratio and rate of dye uptake. These approaches led to predictions from the parameters of the dyebath but they did not specifically pertain to the appearance of the dyed fabric.[3,4]

The concepts of level and union shades are most related to color appearance, measurement and shade sorting. Color measurements rely on instrumentation systems including a spectrophotometric colorimeter and in some cases, a personal computer. Software programs can offer methods of shade sorting based on the Commission Internationale de l'Eclairage (CIE) colorimetry concepts of lightness, L^*, redness or greenness, a^* and yellowness or blueness, b^*. These color parameters are the basis of assigned digit codes with allowable tolerance levels and they offer a method of shade sorting where fabrics with like shade numbers are pieced together.[5] Colorimetry for shade sorting can be applied on-line on textile inspection machines with monitoring capability. Advanced systems for quality control of dyed and finished goods allow increased utilities for meeting the demands of the textile industry's common goal of quick response—where timely color monitoring and final product evaluation are critical. Although colorimetry parameters are used to fully describe color quality, they provide incomplete information on the uniformity of shade.

Machine vision components equipped with optical sensors and signal processors for rapid conversion of raw data into useable format can be placed in sequence with shade sorting instrumentation. High speed, all-purpose computers are effective image processing tools. They are capable of performing mathematical or algorithmic processes on images of natural photographic quality. For example, an image can be analyzed as a two-dimensional function for depiction in gray-scale variations with pictorial information in the form of a histogram. The computer provides great flexibility for image manipulation. In one application, an automated inspection system incorporating a charge coupled device (CCD) camera had been synchronized to a color printing process to detect defects in pattern registry. The system relies on successive image captures of the fabric as it is printed.[6]

Electronic imaging with image analysis has been fully adapted and integrated into microscopy. Complete image processing packages include camera, computer and software. Alternatively, personal computers can be adapted with off-the-shelf frame grabber, extra image memory, image processing capabilities and proprietary software. Since the 1980s, electronic imaging has gained increasing integration into the textile industry for measuring fiber, yarn and fabric properties.[7-13] Since the 1980s, the Wool Research Organisation of New Zealand (WRONZ) has been examining textural changes in carpets under wear conditions.[14-19] In particular, the monochromatic gray scale images of new and worn wool carpet fabrics were examined as gray-level histograms. These histograms were characterized according to gray-level mean (brightness indicator) and standard deviation (contrast indicator). Worn carpets exhibited narrower histograms with higher gray-scale mean values indicating loss of tuft shadow and increased lightness from wear.[15] The histograms were characterized by mean, median intensity and standard deviation. With a narrow distribution of pixel values, mean and median values were similar and standard deviations relatively small. Histograms that were bimodal and/or skewed exhibited relatively large differences in means and median values and the standard deviations of the gray-scale means were large. For the measurement of intrinsic lightness of carpet, the fabric was placed in half the field of view next to a mid-gray fabric occupying the remaining half field. For the measurement of carpet wear, new and worn specimens were similarly positioned. The mean intensities of these images were determined and a percentage lightness ratio was calculated by the ratio of the mean intensity of the sample divided by the mean intensity of the control x 100.[18] It was found that these ratios were indicators of carpet wear by correlations with the lightness parameter, L^*.

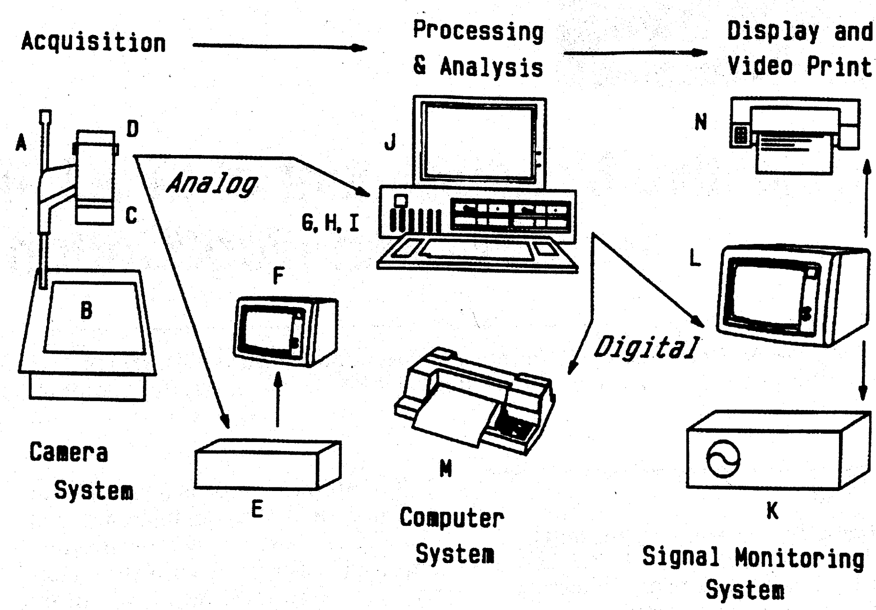

Fig. 1. Schematic for image processing system showing system configuration—copystand, A; light source box, B; zoom camera lens,C; CCD solid state TV camera, D; camera control unit, E; monochrome video monitors, F and L; computer, G; software, H; frame grabber board, I; SVGA color monitor, J; oscilloscope, K; ink jet printer, M; and thermal graphics printer, N.

Materials and Methods

Electronic imaging was applied to two types of dyed fabrics—all wool challis, TF530 (Testfabrics Inc., Middlesex, N.J.)[a] and union cloth of 50/50 wool/cotton with wool warp and cotton fill, TF4504 (Testfabrics Inc.). The fabrics were pretreated and dyed in cooperation with researchers in the Textile Finishing Chemistry Research Unit of the U.S. Department of Agriculture, the Southern Regional Research Center. Pretreatment consisted of applying dimethyloldihydroxyethyleneurea (DMDHEU) and choline chloride (CC) in the same pretreatment padbath with the following different compositions:

4%DMDHEU/6%CC, and
6%DMDHEU/8%CC.

After pad/dry/cure, the fabrics were cut to 4.5" x 5" samples and dyed with C.I. Acid Red 114, C.I. Direct Red 79, C.I. Reactive Red 2 and C.I. Reactive Blue 19 in acidic medium. In the case of cotton fibers, ionic bonding between the cationic cotton (modified with quaternary CC) and the anionic dye was achieved. In the case of wool, typical anionic dyeing prevailed in the acidic medium. The colorimetric lightness parameter, L^* and color strength parameter, K/S, for the dyed unmodified and modified fabrics were analyzed to determine effectiveness of dyeing and digital image analysis to determine union and level shades were used.

The dyed fabrics were imaged with the image analysis system shown in Fig. 1. The package consists of a solid state CCD TV camera which was selected for its compactness, monochrome (black/white) feature and power control features. The software provides a window environment for simultaneous display of the analog images of the fabric and their corresponding digital histograms. Note that the computer and hardware are in line for analog-to-digital conversion of the images. Note also that the oscilloscope continually monitors quality of the image.

When the dyed sample is placed within the light box (360° reflected illumination from light source along top perimeter of box), the analog monitor receives an immediate signal and the image displayed is used to position the fabric, focus the camera and provide a camera system check. The camera features include a zoom lens, with focal length extension of 12.5 mm to 75 mm. Extension tubes and magnification lenses enlarge the image. Yarns in the weave can be resolved at a camera distance of 1.5 inches, with area of interest (AOI) equal to 0.5 inches. The system generates a 1MByte 1024 x 1024 x 8 bit image. To determine union shades, a 1.5" window was imaged, and in the case of level shades a 3.5" window, to fill a 640 (horizontal) x 480 (vertical) pixel frame buffer for a 3"x5" capture window on the digital monitor. A copy stand is used to position the camera so that the optical axis is perpendicular to the plane of the fabric. Manual iris control was used for all imaging. The camera supply unit has a black control to increase brightness for adjusting the histogram along the gray scale axis. This allows the lightest and darkest fabrics to fall within the gray scale range (1 to 255, black to white). All fabrics are imaged under the same optimized control settings. Once the optimum conditions for capturing the image are achieved, no further system modifications are made.

A typical procedure for imaging involves the following steps:

1. Position the fabric in the light box.
2. Determine what viewing distance is required; adjust camera height; affix proper lenses to the camera.
3. View the fabric through the analog monitor for focus and contrast. Adjust lightness/darkness of the image with f-stop settings, focus and zoom camera feature.
4. Select software function for image capture of the live image.
5. Capture the image. The image is now acquired, digitized and stored in the frame buffer.
6. Select software function to process the image to a tagged image format (TIF) file.
7. Histograms are retrieved from TIF files. Data production can only be

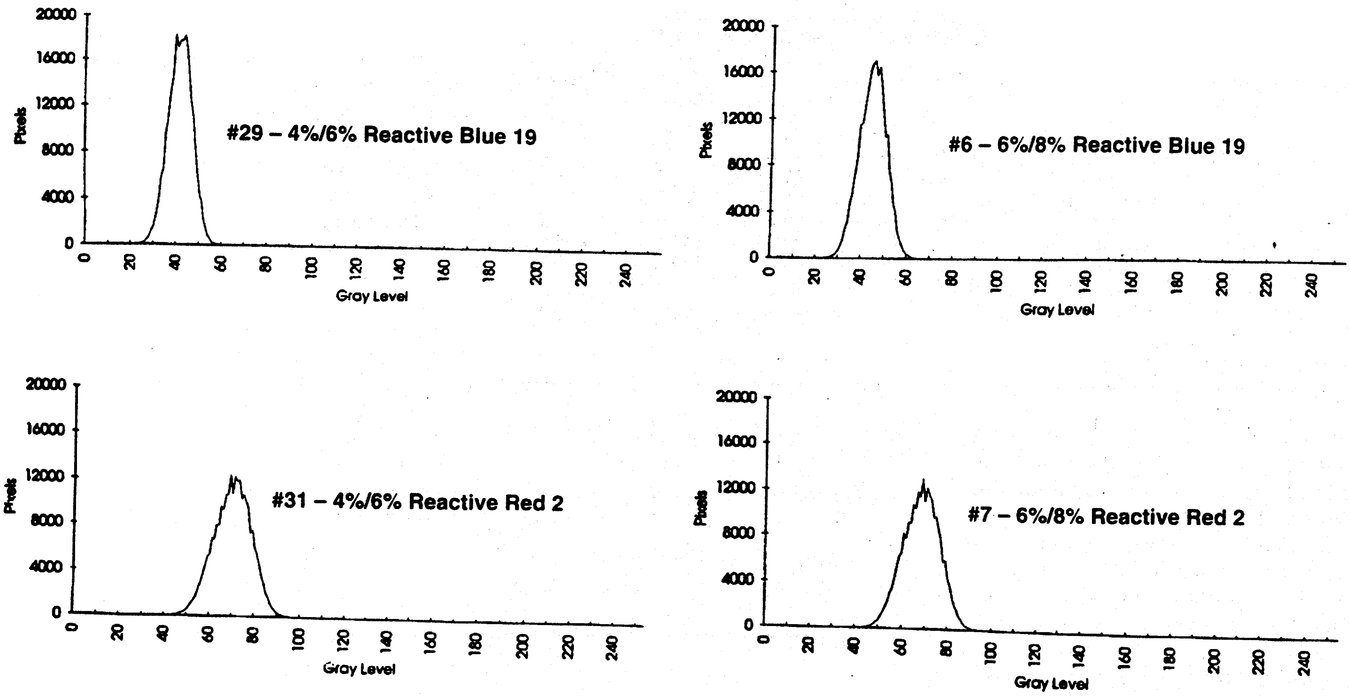

Fig. 2. Level shades—histograms of wool challis dyed at 3.0% owf with C.I. Reactive Blue 19 and C.I. Reactive Red 2 after pretreatments with 4%/6% and 6%/8% DMDHEU/CC.

produced through TIF files manipulated within the system.

Each of the histograms was fitted to a superposition of two or three Gaussian peaks. The fabrics with relatively homogeneous color could be fitted well with two peaks, while the untreated union fabrics clearly required a third peak to adequately represent the peak shape. The curve fitting utilized a nonlinear regression program, Abacus, which was written in-house.[20] To perform this analysis, the user needs to set initial estimates for the height, the peak mean and the peak standard deviation for each Gaussian peak—a total of six or nine parameters for two or three peaks respectively. The program uses the Gauss-Newton iteration algorithm to refine these estimates and select the set of parameter values which minimizes the sum of squares of differences between the data points and the superposition of Gaussian peaks.[20]

Results and Discussion

Level Shade Evaluation

The images of wool challis fabrics were captured and archived as TIF files. They are shown as histograms in Figs. 2 and 3. The breadth of the histogram is reflected in the standard deviation reported in Table I. Note the narrow histograms for fabrics #29 and #6 dyed with C.I. Reactive Blue 19. The fabric image areas were 21x16 mm^2. A polarizing filter was used at a camera dis-

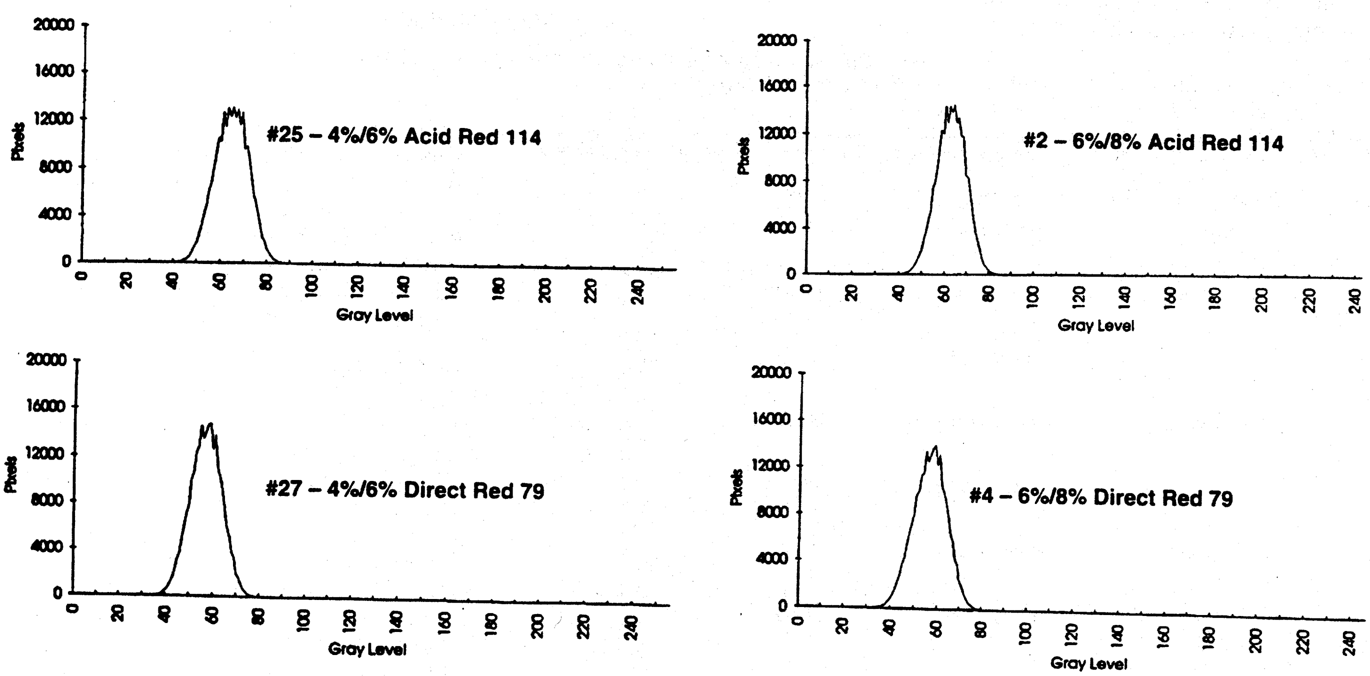

Fig. 3. Level shades—histograms of wool challis dyed at 3% owf with C.I. Acid Red 114 and C.I. Direct Red 79 after pretreatments with 4%/6% and 6%/8% DMDHEU/CC.

Table I. Level Shades—Image Analysis and Colorimetry Parameters for Wool Challis Fabrics

Sample No.	DMDHEU/CC (owf)	Dye	K/S	L*	GS Mean	Std. Dev.	Levelness Index[a]
29	4%/6%	React Blue 19	23.70	21.12	38.72	11.18	110.6
6	6%/8%	React Blue 19	23.30	22.24	41.87	12.18	101.5
31	4%/6%	React Red 2	22.09	38.86	65.75	18.68	66.2
7	6%/8%	React Red 2	21.65	39.22	64.35	18.23	67.8
25	4%/6%	Acid Red 114	27.58	36.02	60.55	17.10	72.3
2	6%/8%	Acid Red 114	28.49	34.68	59.18	16.56	74.6
27	4%/6%	Direct Red 79	26.61	28.16	53.53	15.20	81.3
4	6%/8%	Direct Red 79	25.83	29.55	53.42	15.40	80.3
gray card					164.44	12.36	100.0

[a]S_o = gray card; Lightness Index = $(S_o/S)x100$.

tance of 9.5 inches. Each fabric was imaged five times and averaged for an average histogram. Each histogram represents pixel distribution and its gray scale mean indicates the lightness/darkness similar to an achromic value scale. The standard deviation *S*, is an indication of levelness of shade. In Table I when an 18% photographic gray card is taken as reference for levelness, an index or ratio can be developed as

$$\text{Levelness Index} = (S_o / S) \times 100 \quad \text{Eq. 1}$$

where S_o is the standard deviation of the gray card.

A levelness index of 90.9 (allowing for 9.1% error in system operations) and lower would indicate that the dyed sample's standard deviation is significantly greater than that of the gray card. For example, #31 in Table I would have an index of 12.36/18.68(100) or 66.2%. Compared to the gray card, #31 is unlevel. However, by visual perception, it is uniformly dyed. Clearly, there is no need to push the limits of detection beyond that which the eye can see.

If instead of assigning S_o to the gray card, S_o is taken to be a visually perceived level-dyed fabric, say #27 in Table I, then

$$\text{Levelness Index} = [(S - S_o)/S_o] \times 100 \quad \text{Eq. 2}$$

For example, the levelness index of fabric #31 would be: [(18.68-15.20)/15.20 x 100 = 22.9%. The standard deviation of #31 is 22.9% greater than #27. Nevertheless, #31 appears level. In fact, all fabrics in Table I are visually level. A threshold for levelness could be set at some *S* specific for an unlevel fabric. For relative comparison to the values in Table I, a new fabric set must be imaged under the exact same system conditions. Otherwise, only relative comparisons within the group can be made.

Both colorimetric and image analysis data in Table I and corresponding Figs. 2 and 3 indicate that the dye uptake of the wool challis is approximately the same whether the pretreatment is 4%/6% or 6%/8% DMDHEU/CC. In fact, the pretreated fabrics in Table I were not different in *K/S*, *L** and gray scale mean from their unpretreated counterpart fabrics (not shown). The linear relationship between the color parameter, lightness (L*), and the digital image parameter, grayscale mean (GS), in Fig. 4, shows how colorimetry and digital image analysis would be complementary within the dye/finish range.

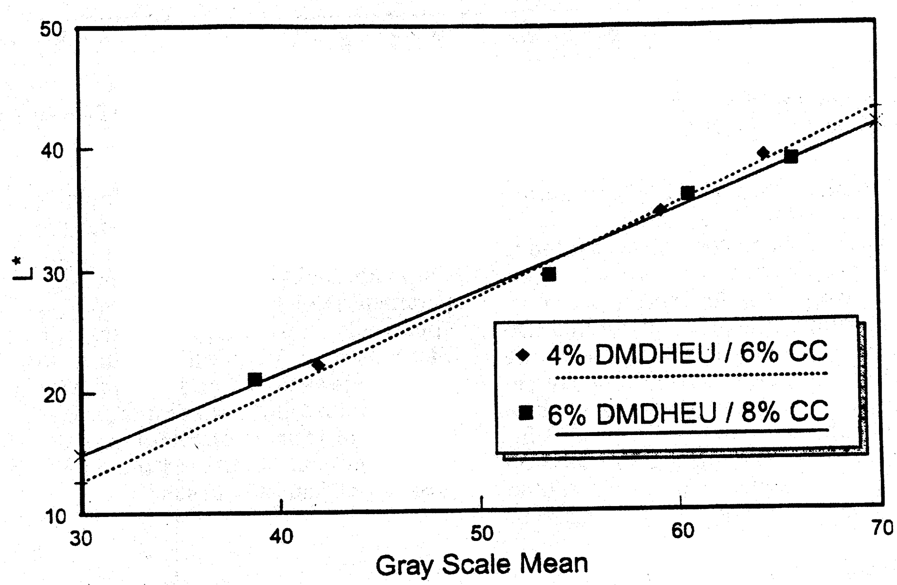

Fig. 4.Correlation between gray scale mean of each dyed fabric histogram with the fabric colorimetry parameter for lightness, *L**.

Table II. Union Shades—Image Analysis and Colorimetry Parameters for Wool/Cotton Fabrics

Sample	DMDHEU/CC (owb)	Dye	K/S	F
23	none	React Blue 19	2.86	57.3 60.1 59.3
37	4%/6%	React Blue 19	18.76	4.0 2.4 2.0
24	none	React Red 2	5.29	19.7 19.7 19.0
40	4%/6%	React Red 2	20.81	6.2 6.3 7.3
20	none	Direct Red 79	16.22	30.6 30.8 30.9
36	4%/6%	Direct Red 79	22.62	5.5 7.9 8.4
18 wool	none	Direct Red 79	26.09	9.3 9.5 10.3
27 wool	4%/6%	Direct Red 79	28.16	10.8 10.6 9.7

Union Shade Evaluation

The wool/cotton union cloth was ideal for visually examining union dyeing because the wool warp fringe color could be compared to the cotton weft fringe color. The fabrics were imaged at a camera distance of 1.50 inches and the AOI equal to 0.50 inches. A polarizing filter and a +4 magnification lens were used. Each fabric was imaged in three different places. The corresponding histograms were fitted to a sum of Gaussian curve shapes to define, union shade index, *F*, as follows:

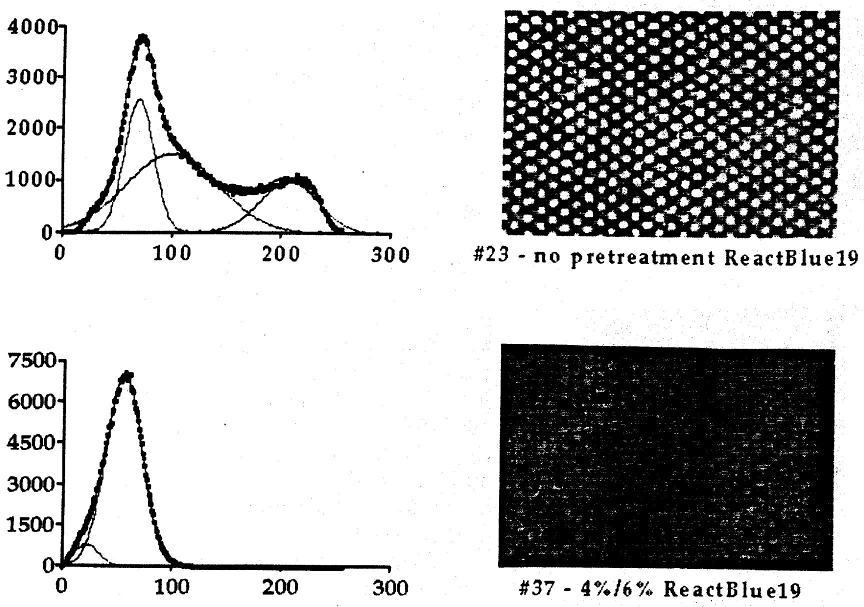

Fig. 5. Comparisons of the image of dyed wool/cotton fabric with its corresponding histogram showing fit to a superposition of two or three Gaussian peaks—the effect of pretreatment on dye uptake with C.I. Reactive Blue 19 at 3% owf (Table I).

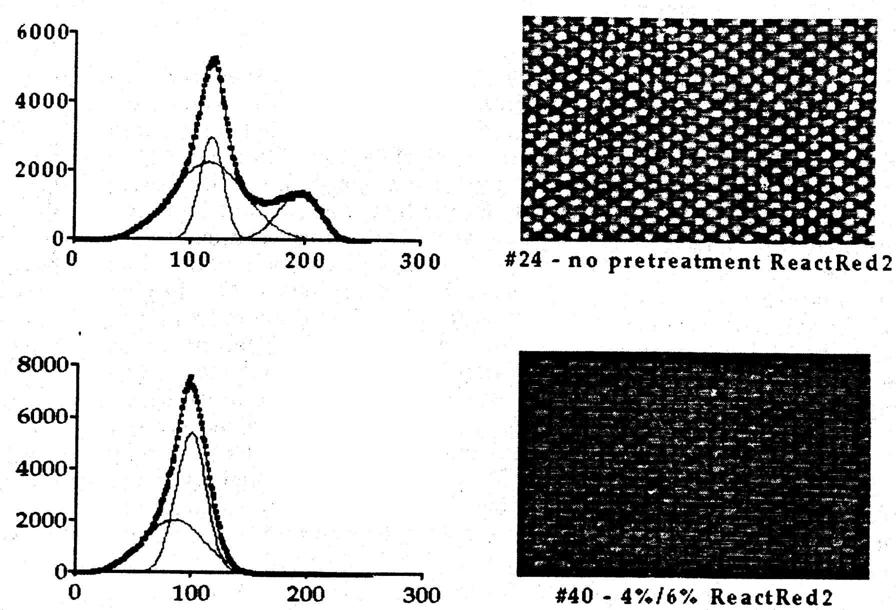

Fig. 6. Comparisons of the image of wool/cotton fabric with its corresponding histogram showing fit to a superposition of two or three Gaussian peaks—the effect of pretreatment on dye uptake with C.I. Reactive Red 2 at 3% owf (Table I).

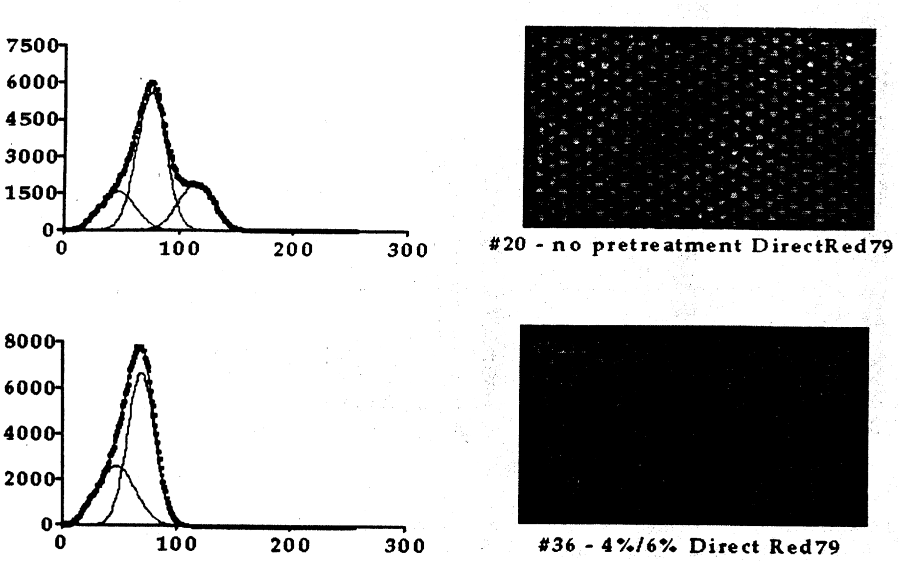

Fig. 7. Comparisons of the image of wool/cotton fabric with its corresponding histogram showing fit to a superposition of two or three Gaussian peaks—the effect of pretreatment on dye uptake with C.I. Direct Red 79 at 3% owf (Table I).

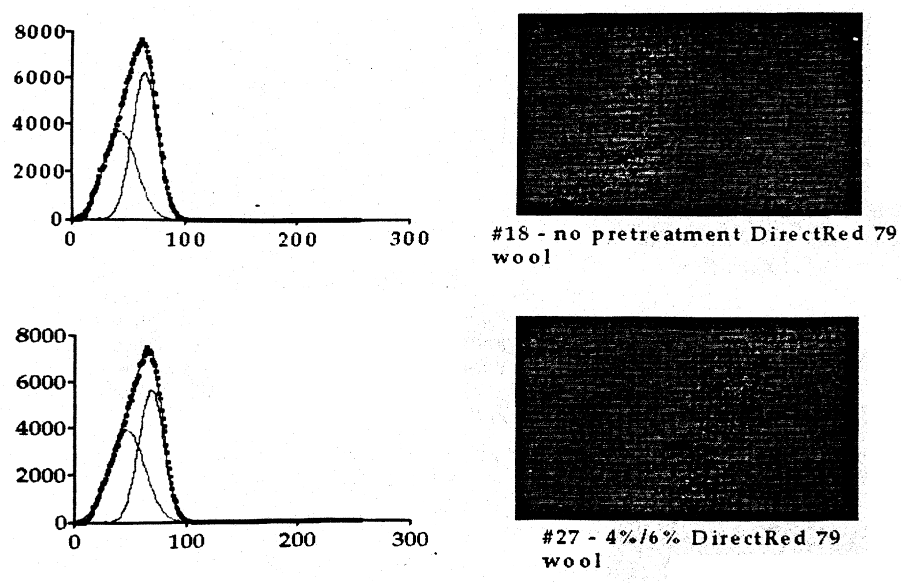

Fig. 8. Comparisons of the image of wool challis with its corresponding histogram showing fit to a superposition of two or three Gaussian peaks—the effect of pretreatment on dye uptake with C.I. Direct Red 79 at 3% owf (Table I).

$$F = (M_{high} - M_{low}) * [P_{small}/(P_{small} + P_{large})] \quad \text{Eq. 3}$$

For the wool/cotton fabrics without treatment, as described in Table II, #23 (Fig. 5), #24 (Fig. 6) and #20 (Fig. 7), the histograms are bimodal. These histograms required three Gaussian peaks to represent the shape. Most other fabrics were well represented as a superposition of two peaks. In the untreated union fabrics, the two outer peaks represent the highlights of the wool and cotton portions of the fabric and the distance between the mean gray scale values of these two peaks, (M_{high} - M_{low}), is a measure of the difference in color between the wool and cotton regions. For the curves fitted to two peaks, in some cases the second peak was rather prominent and distinct, whereas in other cases it was only a small shoulder or adjustment to the main peak. To take this into account, the union shade index, *F*, was adjusted by a factor equal to the ratio of the area, P_{small}, of the smaller of the two outer peaks to the sum of the outer peak areas, (P_{small} + P_{large}). The union shade index, F, is unchanged by either horizontal displacement of the histogram shape or an overall change in height of the histogram.

Figs. 5-8 show the histograms for treated and untreated wool/cotton fabrics and for all wool fabrics, #18 and #27 without and with pretreatment. In these figures and in Table II, low *F* values indicate good union shades. Low *F* values are represented by pretreated and dyed fabrics #37, #40 and #36. The untreated counterparts to these fabrics, #23, #24 and #20, respectively show high *F* values and their fabric images in Figs. 5, 6 and 7 show there is differential dye uptake by the wool warp yarns. Because of dark/light contrast in the image of the weave from which the histogram is generated, the corresponding histograms could be easily resolved into the superpositioned composite peaks enveloped within the main histogram. Note the largest breadth for the histogram of fabric #23 and its corresponding fabric image which in Fig. 5, has the greatest contrast between dyed and undyed yarns. Of all fabrics which received no pretreatment, #20 took up the most dye. Not only is its *K/S* the highest in the group, but this value is somewhat close to the *K/S* of its counterpart, #36. Interestingly, by examining the digital image analysis data, the histogram for #20 is bimodal whereas #36 is symmetrical in Fig. 7. Furthermore, the union shade index, *F*, of pretreated #36 is one sixth the value of unpretreated #20. Clearly this is an example of how digital image analysis can provide information on the unionness of shade which colorimetry cannot.

Table II shows that the wool histograms, #18 (with no pretreatment) and #27 (with pretreatment) in Fig. 8, are similar to the symmetrical and narrow histograms of the wool/cotton, #37, #40 and #36 in Figs. 5, 6 and 7. Also their similar *K/S* and *F* values in #18 and #27 indicate that wool is unaffected by the resin quaternary reagents as discussed above.

Fabrics from Table II are summarized in Fig. 9 according to *F* values for union shades. Assigning the cut-off range for "union" versus "nonunion" can be somewhat arbitrary. Using the fabrics in Table II a range of 11 to 19 can be assigned, below which is union and above which is nonunion.

Conclusion

Digital image analysis was applied to the problem of color nonuniformity as part of ongoing research on wool/cotton blends. In particular, those wet processing problems which seem to limit the use of wool/cotton are being investigated. The application involved dyeing union shades after selective chemical modification by pretreatment of the cotton to make it react like wool in the dyebath. Modification involving resin/quaternary amine can involve migration during pretreatment and this causes nonuniform color within the

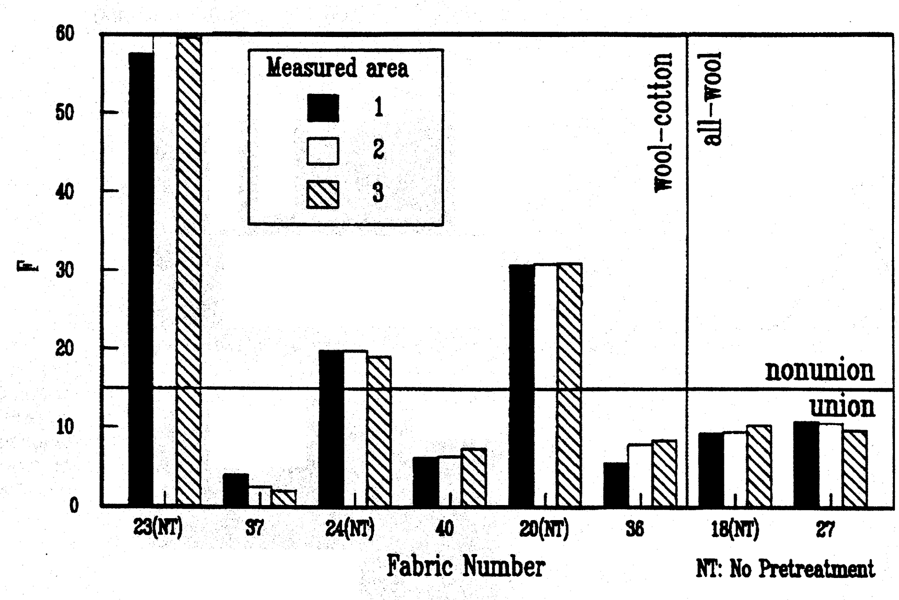

Fig. 9. Union shade index, *F*—three values each for the wool/cotton and wool challis fabrics identified by number on the y-axis and described in Table II.

fabric. Colorimetric analysis with L^* and K/S was found to offer limited descriptions of color uniformity. Thus digital image analysis was used to develop objective measurements for levelness index and union shade index. These indices can be used for basic studies on levelers, dyeing compositions and procedures as well as for applied monitoring in on-line configurations.

In further work it will be necessary to study a greater range of samples to refine the measure of union shade and to correlate the predictive measure with visual measures of unionness. It will also be necessary to study the effect of environmental and instrumental conditions on the methods and measures used to evaluate fabrics. The effect of lighting, focus, camera conditions and other such variables should be considered, since real-world factory conditions may not be readily controlled. Robust quality measures that are relatively unaffected by such changes need to be developed.

The use of the curve fitting is currently more suited for a research laboratory than for rapid on-line sampling. Nevertheless, the computational resources needed to perform nonlinear regressions are not extensive and further research can be expected to develop an automatic method for fitting these curves and deriving quality measures based on these fits completely without human intervention.

Acknowledgments

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