COUNTING WHITE SPECKS USING IMAGE ANALYSIS

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Abstract

White specks are undyed spots on dyed fabric, and are commonly caused by neps. The manual counting of white specks on a fabric is not only a time-consuming process but also inconsistent and prone to error because it is very subjective. In this study, a white speck counter was designed using image analysis techniques to count and size white specks on dyed fabric. It can minimize the variations from light fluctuations, and automatically perform threshold determination and calibration. The performance of the white speck counter was compared with that of the traditional manual counting of white specks on the sample fabrics in terms of accuracy, repeatability and sensitivity to different operators. The white speck counter identified white specks faster and more efficiently than the manual counting method. The white speck counter also performed more consistently and objectively than the manual counting method.

Introduction

White specks are undyed spots on dyed fabric. Since uniform surface color is a desirable aspect for dyed fabric, the occurrence of white specks is detrimental to fabric quality. Supak (1992) reported that white specks found in dyed goods are commonly caused by neps, which are entangled knots of immature fibers. Goynes et al. (1994) reported that undeveloped fibers have a flat, ribbon-like structure because they are composed of only a very thin primary wall, or primary wall and beginning layers of a secondary wall. They stated that due to low cellulose content of the undeveloped, flat, ribbon-like fibers, clumps of these fibers do not accept dye. This results in a white speck in finished, dyed fabrics.

The process of counting neps is very tedious and time consuming. Since the late thirties, neps were counted manually using a back light (Helliwell, 1938) or a black background (Saco-Lowell, 1942). Harrison and Bargeron (1986) compared four methods of nep determination: (1) card web neps, (2) document folders with template-defined viewing area, (3) Agricultural Marketing Service (AMS) nep test machine, and (4) yarn neps (Uster). They concluded that all four tests yielded similar counting results, but all the processes were very tedious and time consuming.

Since it is so time consuming to inspect the whole fabric manually, various research efforts have studied random sampling procedures for visual inspection. Hughs et al. (1988) divided each length of cloth corresponding to one test lot into three areas. Each of these areas was further divided into twelve sections. A 2.54 cm square glass was then randomly laid down on three of the twelve sections from each area and the number of dyeing imperfections were counted. Cheek et al. (1990) placed a template containing 36 cells of 6.45 cm^2 each over the dyed knit fabric. The number of undyed neps was counted within each selected square. Smith (1991) used a circular black cardboard mask with a 6 in^2 opening and a black background behind the sample. He made individual counts from eight different 6 in^2 areas within the sample area. These manual counting methods are not only time-consuming processes but are also inconsistent and prone to error because they are very subjective.

Recently, many studies focused on automatic counting of neps and white specks. Ghorashi et al. (1994) used the AFIS nep module to count and to size neps. Baldwin et al. (1995) used another AFIS module to detect seed coat neps in cotton. Jones and Baldwin (1996) also used the AFIS module to classify neps into fiber neps or fiber entanglements and seed coat neps. They concluded that the AFIS Nep Classification module was able to count and to size seed coat neps by identifying the distinct electrical waveforms produced by fibers, fiber clumps and seed coat neps. Bel-Berger et al. (1994, 1995, 1996) used three different image processing hardware devices in analyzing the number and area of white specks found in dyed fabric. The area of white specks was calculated in terms of number of pixels, but their instrument was not calibrated in length or area to measure the absolute area of white specks. They segmented the image of fabric into a binary image by manually adjusting the threshold value on every image. Manual thresholding is very subjective and prone to variations from operator to operator and from one lighting condition to the other.

Lambert et al. (1997) developed a robust image analysis system to count and to size white specks on dyed fabric that can minimize the variations from light fluctuations and automatically perform threshold determination and calibration. They used a stand-alone illumination chamber to provide uniform illumination on the fabric surface by blocking ambient light and furnishing a consistent light source. They also employed an automatic thresholding routine based on statistical distribution of gray scale intensities. They reported that the white speck counter identifies white specks faster and more consistently than the manual counting method. Due to low magnification of the image, however, many white specks consisted of just one

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pixel, which made it hard to distinguish true white specks from artifacts of random noise.

The objective of this study was to improve the white speck counter developed by Lambert et al. (1997) by using a higher image magnification ratio and other minor modifications. The performance of the modified white speck counter was compared with those of the original white speck counter and of the manual counting method.

Materials and Methods

Illumination Chamber and Imaging Hardware

To provide uniform illumination on the fabric surface by blocking ambient light and furnishing a consistent light source, the illumination chamber made by Lambert et al. (1997) was used. A schematic diagram of the illumination chamber is shown in Figure 1. The image processing hardware included a PCVISION*plus* frame grabber board (Imaging Technology, Inc.), running on a 50 MHZ 80486 microcomputer. The frame grabber has a 512x480 spatial resolution with 256 gray levels. Images were captured by the same black-and-white CCD camera (Pulnix[7] Model TM-7CN), but Fujinon HF35A-2 lens with 35 mm focal length was used instead of a 16 mm lens (Fujinon HF16A-2) used by Lambert et al. (1997).

Image Analysis

Image analysis software to count the number of white specks and to measure the area of individual white specks was developed in Microsoft C language with Itex PC*plus* image processing library. The image analysis procedure starts with acquiring a 6.45 cm^2 (1 in^2) area in the middle of a randomly placed fabric. Exact pixel dimensions of the area are determined automatically from the area calibration result. This 6.45 cm^2 (1 in^2) area is referred to as *Area of Interest* (AOI). The acquired image is then transformed into a binary image by a threshold segmentation. The threshold routine calculates the average and the standard deviation of gray level intensities in the AOI, and adjusts the threshold value automatically according to the following formula:

$$Th\_val = \mathrm{INT}[\, Avg + Alpha * Std + 0.5 \,] \qquad (1)$$

where, *Th_val* is the suggested threshold value, *Avg* and *Std* are the average and the standard deviation of gray level intensities in the AOI, and the *Alpha* is the multiplication factor determined by the exposure calibration. The INT function with the addition of 0.5 rounds up the threshold value to a nearest whole number. The thresholded image is displayed side by side with the original, unthresholded image to facilitate a visual comparison to an operator. The typical screen with the original AOI and the thresholded image is shown in Figure 2. The threshold value can be changed by the operator if the thresholded image does not conform with the operator=s judgment. Usually, little adjustment was necessary when the instrument was properly calibrated.

The thresholded image is then analyzed for white specks by scanning through the AOI and finding objects with white pixels on a dark background. Size, location, and centroid of each object are computed during the scan, as well as minimum and maximum X and Y coordinates which defines the circumscribing rectangle aligned with the scan direction (known as a *Feret Box*). After all objects are identified in the AOI, the program sorts out and eliminates objects smaller than *minimum object size*. It was assumed that objects smaller than *minimum object size* are artifacts of random noise. Preliminary tests showed that most of the true white specks consisted of more than two pixels. Therefore, the initial value of the *minimum object value* was set to two pixels, but can be changed anytime when deemed necessary.

Total number and area of white specks are calculated and displayed at the bottom of the screen. Percent total area is also calculated as the percent ratio of total area of white specks to 6.45 cm^2 (1.0 in^2) AOI. To improve the operator's productivity, the image analysis result is appended to a data file along with the operator's name and the sample identification code. This eliminates a paper form that the operators ordinarily had to fill out. The data file can be easily imported into a spreadsheet program for immediate analysis.

Calibration of White Speck Counter

The information reported by the image analysis algorithm is valid only when the instrument is properly calibrated. Every time the image analysis software is invoked, the computer screen displays date and time the instrument was last calibrated and provides the opportunity for re-calibration. If the camera has been moved or changed in any way after the last calibration, or a new light bulb is installed, or the dye of the fabric is different, a new calibration is needed.

The calibration routine performs two kinds of calibrations - the area calibration and the exposure calibration. The area is calibrated by using a specially prepared "calibration block,"@ which has a 2.5 cm x 2.5 cm (1"x1") black rectangular block on a white background. The image of the calibration block is thresholded into a binary image using an iterative automatic threshold technique implemented by Choi et al. (1995). The number of pixels inside the rectangular block is counted to calculate the pixel-to-area conversion factor. The typical pixel-to-area conversion factor in the initial calibration was 160.0 pixels/mm^2 (103,200 pixels/in^2), compared to 24.29 pixels/mm^2 (15,670 pixels/in^2) of the original white speck counter.

The exposure calibration includes adjusting the camera exposure and setting an initial threshold value. With a sample fabric with known white specks in the field of view, the f-stop of the camera is adjusted so that white specks and the background fabric show up with good contrast. The image is then thresholded, and the threshold value is adjusted until the known white specks show up distinctively. All the small background noises don't have to be eliminated during the threshold, because small objects less than the *minimum object size* will not be counted as white specks in the image analysis. The final threshold value is used to calculate the multiplication factor *Alpha* in Equation (1). The exposure calibration is repeated three times with different parts of the sample fabric so that the calibration can represent the whole fabric. The multiplication factor *Alpha* is set to the average of three repetitions.

Testing Procedure

To compare the performance of the modified white speck counter with those of the original white speck counter and the manual counting method, two operators conducted the same set of experiment performed by Lambert et al. (1997) using the modified white speck counter. As in the previous test, two rolls of sample fabric were obtained from the USDA Cotton Quality Research Station in Clemson, South Carolina. Roll number MQ-294 was considered to be of a low white speck count. Roll number MQ-279 was considered to be of a medium to high white speck count. From each roll of cloth, ten lots were used for the experiment. Lots 1, 4-6, 10-12, and 16-18 were chosen from roll number MQ-294 and lots 721 through 730 were chosen from roll number MQ-279.

In the previous test, the manual counting of white specks was performed using a magnifying lamp and a counting template. The template is a 10.2 cm (4") high and 16.5 cm (6 2") long black metal plate, and has a slit of 10.2 cm (4") wide and 0.635 cm (3") high so that the number of white specks in 6.45 cm^2 (1.0 in^2) area can be counted. The fabric was placed on a slanted table and the template was placed on the fabric at random within a test lot. The number of white specks was then counted within the slit on the template. Twenty different locations were examined at random within a test lot. The counts of white specks at each random location were summed together to determine the total number of white specks in 20 in^2. The same procedure was used for ten test lots on each of the two fabric rolls. The entire measurement procedure was repeated six times.

The original white speck counter counted white specks in a 2 in^2 area. Ten different locations were selected at random within a test lot for a total area of 20 in^2. The total number of white specks in the 20 in^2 area was compared with that from the manual counting method. The same procedure was used for ten test lots on one of the fabric rolls. The whole process was repeated six times before the second roll was tested.

Since the modified white speck counter counts white specks in an 1 in^2 area as in the manual counting method, twenty different locations were examined at random within a test lot. The same procedure was used for ten test lots on one of the fabric rolls. The whole process was repeated six times before the second roll was tested. The total number of white specks in each lot was compared with that of the original white speck counter and the manual counting method using the SAS procedures GLM and LSMEANS.

Results and Discussion

In addition to the ease of use and better reporting capability, the major difference between the original and the modified white speck counter was its image magnification ratio. In the original white speck counter, 12.90 cm^2 (2 in^2) of AOI consisted of about 32,000 pixels in the image. On the other hand, 6.45 cm^2 (1 in^2) AOI of the modified white speck counter consisted of about 103,000 pixels in the image. The operators interviewed after the experiment described that the higher magnification ratio of the modified speck counter helped them to detect true white specks better than the original white speck counter. One potential problem of the higher magnification ratio was the fact that the image may show more white specks than those that can be seen by visual inspection.

Figures 3 and 4 show the average white speck counts of each lot in rolls MQ-294 and MQ-279 measured by the manual counting methods (MAN), the original white speck counter (WSC) and the modified white speck counter (MWSC), by two operators (1 and 2). Each individual white speck count in the figures is the average of six repetitions. Statistical analyses showed that there was a highly significant difference among the three counting methods, and a significant difference between operators. Detailed comparison between counting methods and operators can be performed with the least-squares means (LSMEANS) analysis.

Table 1 shows the least-squares means and corresponding p-values for roll MQ-294, which has a relatively low number of white specks. The p-values show the level of significance that two least-squares means are the same. From the table, we can conclude that the manual counting method is significantly different from the two white speck counter methods, but the original and the modified white speck counter were not significantly different. Furthermore, two operators using the original and the modified white speck counters had virtually the same results, although the two operators using the manual counting method were also not significantly different.

For roll MQ-279, which has a higher number of white specks than roll MQ-294, the difference is more pronounced. Table 2 shows the least-squares means and corresponding p-values for roll MQ-279. All three counting methods were highly significantly different. As can be seen from Figure 4, the modified white speck counter significantly overestimated the number of white specks compared to the other two counting methods. It was observed that many white specks shown in the image were too small to be easily detected by human eye. However, the two operators with extensive experience in manually counting white specks confirmed that those small white specks were true white specks and that they can recognize them on the fabric once they see them on the screen.

Table 2 also shows the variability between the operators. Differences between the two operators using the manual counting method were highly significant, whereas the differences between operators using the two white speck counters were not significant. Therefore, it was concluded that the white speck counter performed more consistently and objectively than the manual counting method.

Conclusions

The modified white speck counter performed better than the original white speck counter in detecting true white specks due to its higher magnification ratio. The operator interface and its automatic reporting capability were also improved to increase operator's productivity. Compared to the manual counting method, the white speck counter counted white specks faster and more efficiently than the manual counting method. The white speck counter also performed more consistently and objectively than the manual counting method.

For the fabric with relatively high numbers of white specks, the modified white speck counter generally overestimated the number of white specks compared to the other two counting methods. However, visual inspection confirmed that the overcounted white specks were true white specks, although hard to detect with a human eye. Considering that the white specks are visual imperfections on a fabric, counting small white specks that are hard to see with a human eye may not be desirable. However, the modified white speck counter can still be adapted for such a situation by adjusting the *minimum object size* during the calibration process or anytime during the measurement. Any object smaller than the *minimum object size* will be considered artifacts of random noise, and will not be counted as white specks. The decision may depend on whether it is desirable to count any true white specks or to duplicate visual inspection as close as possible.

Disclaimer

Mention of specific products is for information only and not to the exclusion of others that may be suitable.

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Table 1. Least-squares means and corresponding p-values for roll MQ-294.

			MANUAL		WSC		MWSC	
			OP1	OP2	OP1	OP2	OP1	OP2
		LSMEAN	17.08	18.28	22.73	23.08	20.68	20.55
MAN	OP1	17.08	-	0.4262	0.0005	0.0002	0.0202	0.0250
	OP2	18.28	0.4262	-	0.0047	0.0024	0.1153	0.1364
WSC	OP1	22.73	0.0005	0.0047	-	0.8159	0.1770	0.1510
	OP2	23.08	0.0002	0.0024	0.8159	-	0.1153	0.0970
MWSC	OP1	20.68	0.0202	0.1153	0.1770	0.1153	-	0.9293
	OP2	20.55	0.0250	0.1364	0.1510	0.0970	0.9293	-

Table 2. Least-squares means and corresponding p-values for roll MQ-279.

			MANUAL		WSC		MWSC	
			OP1	OP2	OP1	OP2	OP1	OP2
		LSMEAN	40.68	57.07	55.00	57.95	75.56	76.80
MAN	OP1	40.68	-	0.0001	0.0001	0.0001	0.0001	0.0001
	OP2	57.07	0.0001	-	0.2981	0.6549	0.0001	0.0001
WSC	OP1	55.00	0.0001	0.2981	-	0.1399	0.0001	0.0001
	OP2	57.95	0.0001	0.6549	0.1399	-	0.0001	0.0001
MWSC	OP1	75.56	0.0001	0.0001	0.0001	0.0001	-	0.5331
	OP2	76.80	0.0001	0.0001	0.0001	0.0001	0.5331	-

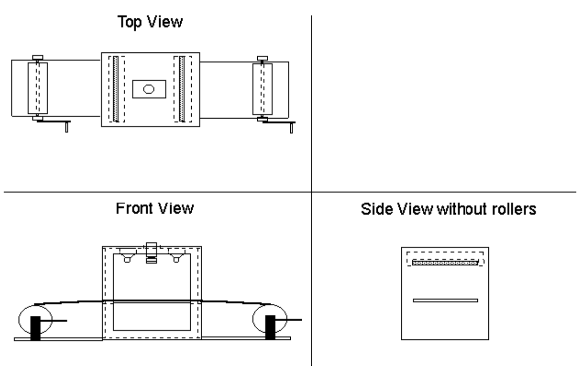

Figure 1. Schematic diagram of the illumination chamber.

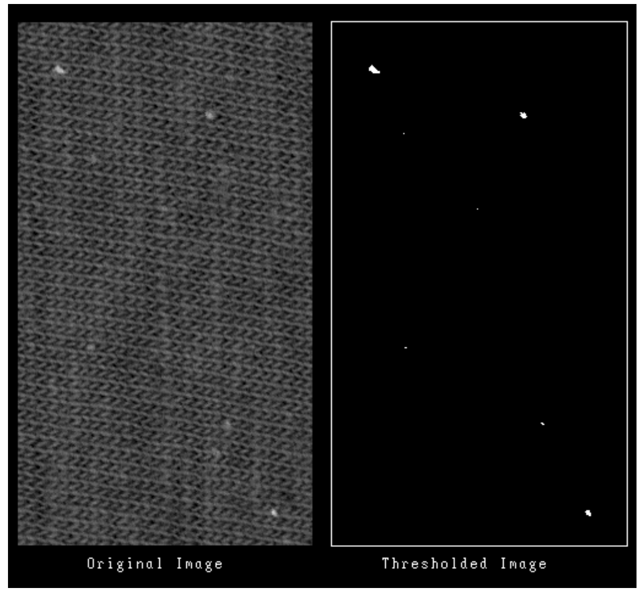

Figure 2. Example screen of original AOI and thresholded image.

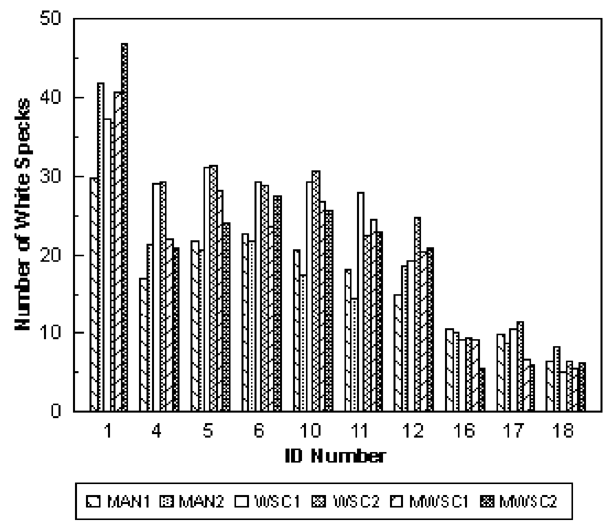

Figure 3. Average number of white speck counts on roll MQ-294.

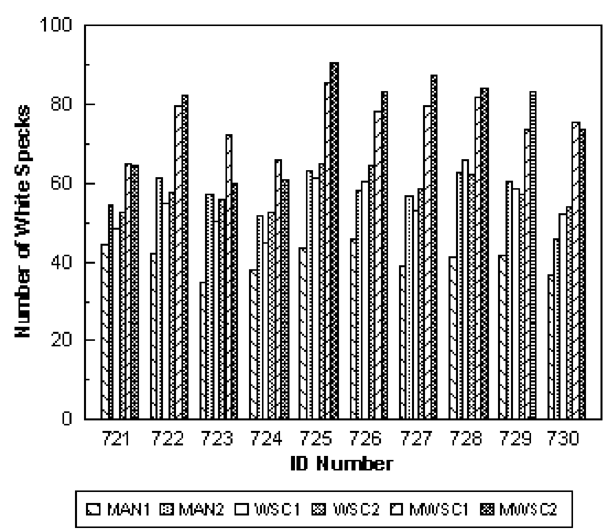

Figure 4. Average number of white speck counts on roll MQ-279.