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TEXTILE PROCESSING

White Speck Detection on Dyed Fabric Using Image Analysis

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INTERPRETIVE SUMMARY

White specks are undyed spots on dyed fabric, and are commonly caused by neps. According to American Society for Testing and Materials (ASTM D123-96, 1996), a nep is "a tightly tangled knot-like mass of unorganized fibers." Due to low cellulose content of the neps, clumps of these fibers do not accept dye. Therefore, when a fabric is dyed, the mechanical and biological neps formed by fine or immature fibers create undyed spots in the finished fabric. These undyed spots are known as white specks.

Quality of a finished garment is determined by, among other things, the number of imperfections contained within the fabric. The more imperfections found in the cloth, the less value added the product has from the manufacturer. Since uniform surface color is a desirable aspect for fabrics, the inclusion of white specks is detrimental to fabric quality. The process of counting white specks is very tedious and time consuming. Since the late 1930s, white specks were counted manually using a back light or a black background. Even today, white specks are being counted manually relying on visual inspection. The manual counting is not only a tedious and time-consuming process but also inconsistent and prone to error because it is very subjective. In this research, a robust image analysis system was developed to count and size white specks on dyed fabric that can minimize the variations from light fluctuations and automatically perform threshold and calibration.

The white speck counter developed in this research consists of three major components: an illumination chamber, fabric transport mechanism, and image processing hardware and software. The illumination chamber is needed to provide uniform illumination on the fabric surface by blocking ambient light and furnishing a consistent light source. An aluminum roller is mounted on each side of the chamber so that a roll of dyed fabric can be mounted on a roller on one side of the chamber, and transported through the chamber to the other side onto the second roller. An image of the fabric is then captured by a black-and-white camera. Image analysis software counts the number of white specks in the image and measures the area of individual white specks.

The performance of the white speck counter was compared with that of the traditional manual counting of white specks in terms of accuracy, repeatability, and sensitivity to different operators. Two different operators inspected 20 test lots on two fabric rolls using the white speck counter and 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.

ABSTRACT

White specks are undyed spots on dyed fabric, and are commonly caused by neps. Since quality of a finished garment is determined by, among other things, the number of imperfections contained within the fabric, the inclusion of white specks is detrimental to fabric quality. The manual counting of neps is not only a time-consuming process, but also inconsistent and prone to error because it is very subjective. In

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Abbreviations: AFIS, Advanced Fiber Information System; ASTM, American Society for Testing and Materials.

this study, an image analysis system was developed to count and size white specks on dyed fabric that can minimize the variations from light fluctuations and automatically perform threshold and calibration. The performance of the white speck counter was compared with that of the traditional manual counting of white specks in terms of accuracy, repeatability, and sensitivity to different operators. Two different operators inspected 20 test lots on two fabric rolls using the white speck counter and 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.

White specks are undyed spots on dyed fabric, and are commonly caused by neps. According to the American Society for Testing and Materials (ASTM D123-96, 1996), a nep is "a tightly tangled knot-like mass of unorganized fibers." This is to be differentiated from a mote, which is another impurity found in cotton (*Gossypium hirsutum* L.) consisting of a seed fragment encompassed by cotton fibers. Many researchers have studied neps over the decades, including types, formation, effects, and solutions. Watson et al. (1991) classified neps into two groups, mechanical and biological, and observed that mechanical neps are similar to the classical ASTM definition, where they are formed from mechanical actions on the fibers. They also reported that fibers with low micronaire values tend to form mechanical neps because the fibers are finer and less mature, and are therefore less rigid. Biological neps are clumps of very immature fibers that can be found in seed cotton before mechanical processing has occurred. They also reported that fibers with low micronaire values (finer and immature fibers) tend to form mechanical neps because of the weak, poorly developed, less rigid fibers. Goynes et al. (1994) reported that because of low cellulose content of the undeveloped, flat, ribbon-like fibers, clumps of these fibers do not accept dye. Therefore, when a fabric is dyed, the mechanical and biological neps formed by fine or immature fibers create undyed spots in the finished fabric. These undyed spots are known as white specks.

Quality of a finished garment is determined by, among other things, the number of imperfections contained within the fabric. The more imperfections found in the cloth, the less value can be added to the product by the manufacturer. Since uniform surface color is a desirable aspect for fabrics, the inclusion of white specks is detrimental to fabric quality. White specks are a result of neps being included in the raw cotton product supplied to a processor or result from ensuing mechanical treatment.

The process of counting neps is very tedious and time consuming. Since the late 1930s, neps were counted manually using a back light (Helliwell, 1938) or a black background (Saco-Lowell, 1942). Even today, neps are being counted manually relying on visual inspection (Harrison and Bargeron, 1986; Hughs et al., 1988; Cheek et al., 1990; Smith, 1991). The manual counting is not only a time-consuming process, but also inconsistent and prone to error because it is very subjective.

Recently, many studies focused on automatic counting of neps and white specks. The Advanced Fiber Information System (AFIS) module has been used by many researchers to detect and count seed coat neps (Ghorashi et al., 1994; Baldwin et al., 1995; Jones and Baldwin, 1996). Mor (1996) introduced a fiber contamination tester that detects sticky deposits by an electro-optical device and evaluates nonsticky parameters such as neps, trash, and seed coat fragment using an image processing system. Bel-Berger et al. (1994, 1995, 1996) used three different image processing hardware systems 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. Although they were able to measure the relative area of white specks to the whole fabric, called percent white, 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.

The objective of this study was to develop a robust image analysis system to count and size white specks on dyed fabric that can minimize the variations from light fluctuations, and automatically perform threshold and calibration.

MATERIALS AND METHODS

Design of White Speck Counter

The white speck counter developed in this research consists of three major components: an illumination chamber, fabric transport mechanism, and imaging hardware. The illumination chamber was needed to provide controlled illumination on the fabric surface by blocking ambient light and furnishing a consistent light source. A schematic diagram of the illumination chamber is shown in Figure 1. It was constructed of high quality 1.3 cm (½ in) plywood, and is 58.4 cm (23 in) high, 47.0 cm (18 ½ in) wide, and 52.1 cm (20 ½ in) deep. Approximately 24.1 cm (9 ½ in) from the top, a slit was cut 31.8 cm (12 ½ in) long by 2.5 cm (1 in) high in both sides of the chamber in order for the fabric to pass through the chamber. Then a 3.2 mm (⅛ in) aluminum plate was installed through the side slits and curled downward at the outside walls. The plate was to provide a flat, smooth surface for the fabric to slide on. An adjustable sliding shield was mounted above each slit so that the slits can be covered from ambient light after fabric was fed through. Two 45.7 cm (18 in) long fluorescent lamps were placed 17.8 cm (7 in) apart inside the top center of the chamber, and the camera was mounted at the top center of the chamber at a distance of 26.4 cm (10 ⅜ in) from the fabric.

The illumination chamber was attached to a 1.3 cm (½ in) thick board approximately 102.9 cm (40 ½ in) wide and 52.1 cm (20 ½ in) deep. An aluminum roller was mounted on each side of the chamber at 16.5 cm (6 ½ in) high from the base board and 22.9 cm (9 in) from the side of the chamber. The roller can hold a fabric roll of 15.2 cm (6 in) in diameter. A roll of dyed fabric can be mounted on a roller on one side of the chamber, and transported through the chamber to the other side of the chamber onto the second roller. After inspecting one side of the fabric, the rolled fabric can be flipped and fed back to the chamber in the opposite direction to inspect the other side of the fabric. The height of

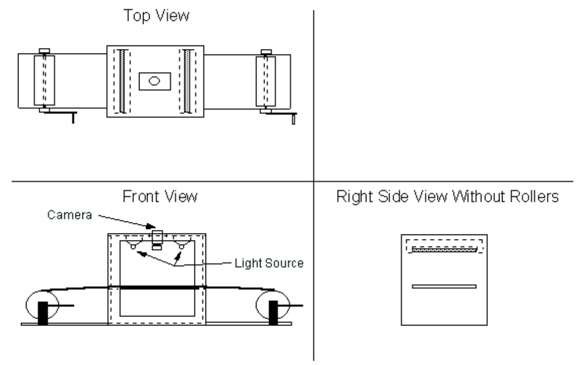

Fig. 1. Schematic diagram of the illumination chamber.

the inspection plane where the image of the fabric is taken was designed to be higher than the top of the roll of fabric so that fabric surface stays flat on the inspection plane.

The image processing hardware included a PCVISION*plus* frame grabber board (Imaging Technology, Inc.)[1], running on a 50 MHZ 80486 microcomputer. The frame grabber has a 512 x 480 spatial resolution with 256 gray levels. Images were captured by a black-and-white CCD camera (Pulnix Model TM-7CN) with Fujinon HF16A-2 lens with 16 mm focal length and displayed on an RGB analog monitor (Sony Model PVM-1271Q).

Image Analysis

Image analysis software to count the number of white specks and 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 an image of randomly placed fabric. Three consecutive frames of the same image were acquired and averaged to reduce electrical noise in the acquired image. A rectangular area of 2.5 (1 in) by 5.1 cm (2 in) in the middle of the field of view is used for white speck inspection. This 2.5 (1 in) by 5.1 cm (2 in) area is referred to as area of interest. For archiving purposes, images can be saved into a file and recalled later for further processing. When a roll of fabric is inspected continuously, each image does not have to be stored for subsequent processing.

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

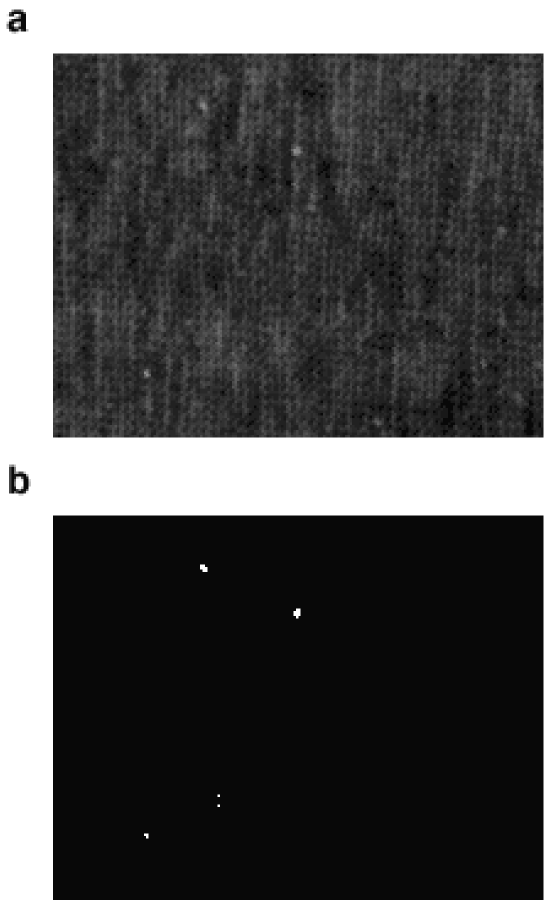

Fig. 2. Typical images of dyed fabric. (a) gray scale image and (b) thresholded image.

The second step in the image analysis procedure is a threshold segmentation to make a binary image of the fabric. The threshold routine calculates the average and standard deviation of gray level intensities in the 2.5 (1 in) by 5.1 cm (2 in) area of interest, and adjusts the threshold value automatically according to the following formula:

$$Th\_val = INT\ [Avg + Alpha * Std + 0.5] \quad [1]$$

where Th_val is the suggested threshold value, Avg and Std are the average and standard deviation of gray level intensities in the area of interest, and Alpha is the multiplication factor set in the exposure calibration. The usual range of Alpha was between 3.0 and 4.0. The thresholded image of area of interest is moved to the top part of the screen and shown with the original, unthresholded image, side by side, to facilitate an operator's visual comparison. If deemed necessary, the operator can adjust the threshold value using up/down arrow keys until all known white specks show up distinctively. Usually little adjustment is necessary when the instrument is properly calibrated. A typical gray scale image of dyed fabric and the thresholded image are shown in Figure 2.

The thresholded image is now ready for image analysis in which the area of interest is scanned and objects with white pixels on a dark background are found. Size, location, and centroid of each object are computed during the scan, as well as minimum and maximum X and Y coordinates that define the circumscribing rectangle aligned with the scan direction (known as a *Feret Box*). After all objects are identified in the area of interest, the program sorts out and eliminates objects smaller than minimum object size. It was assumed that objects smaller than minimum object size were artifacts of random noise. The initial value of the minimum object value is set to two pixels, but can be changed in the software. 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 12.9 cm^2 (2.0 in^2) area of interest. Detailed information about each white speck, such as size, location, centroid, and *Feret Box* coordinates can also be inspected on screen and written to a file.

Any saved images can also be printed either in gray scale or binary on a HP PCL4 (Hewlett-Packard Printer Command Language 4) compatible printer, at 300 dpi resolution. The algorithm to print a gray scale image was based on the ordered dither method with constrained "verage" edge enhancement that Jarvis and Roberts (1976) reported. The standard 4 x 4 dither matrix was modified to a 4 x 3 dither matrix to accommodate the 4 to 3 aspect ratio of the image pixel used. To print a binary image, each pixel in the image was translated into 4 x 3 blocks of the same or opposite color.

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 the 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 has been 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 x 5.1 cm (1 x 2 in) black rectangular block on a white background. The image of the calibration block is thresholded into a binary image, and all black pixels are counted to calculate the pixel-to-area conversion factor. An iterative automatic threshold selection technique implemented by Choi et al. (1995) was used to set the threshold value automatically without operator intervention. The typical pixel-to-area conversion factor in the initial calibration was 24.29 pixels/mm^2 (15 670 pixels/in^2).

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 do not 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. A typical value for multiplication factor, Alpha, in the initial calibration was between 3.0 and 4.0.

Testing Material

Two rolls of knitted fabric were used in testing the white speck counter's performance to count the number of white specks accurately and nonsubjectively . The sample fabric was obtained from the USDA Cotton Quality Research Station in Clemson, SC. 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. Each roll contained several different lots, each lot consisting of a different cotton variety, but dyed with the same dye color and dying conditions. Usually, different cotton types have different nep and white speck occurrences due to the maturity, harvesting, and mechanical processing of the cotton.

Roll formation is a standard procedure used by the USDA. The process created a random test roll made of several different varieties or types of cotton in the form of lots. A wide range of cottons come to the USDA in bales. Two lots are formed from a bale upon arrival. Each lot from the bale is then given a replication number. One lot of the cotton bale is then divided among three hoppers that thoroughly mix the cotton for a homogeneous cotton mixture. The homogeneous cotton mixture is then spun into yarn.

One yard of fabric is made for each lot of spun yarn. To form a test roll, several lots from different cotton varieties or types chosen at random are grouped giving each lot a number unique to that test roll and test lot. The first yard of fabric is knitted using one of the randomly selected lots. When the first yard of fabric has been completed, a black yarn marker is woven into the fabric to signify the change in lots and the lot's unique number is printed on the fabric using a permanent marker. The next yard of fabric is knitted from another randomly selected lot. The roll of fabric is continuously formed until all randomly selected lots are knitted and each lot marked with the unique number and separated by the black yarn marker. The roll is then dyed using a direct blue dye. The direct blue dye is very sensitive to white specks, allowing for a better viewing of the white specks vs. dyed fabric.

From each roll of cloth, 10 lots were chosen for the experiment. The lots chosen from MQ-294 represented fabrics with a relatively low number of white specks and the lots chosen from MQ-279 represented fabrics with a range of medium to high number of white specks. Lots 1, 4 to 6, 10 to 12, and 16 to 18 were chosen from roll number MQ-294 and lots 721 through 730 were chosen from roll number MQ-279.

Testing Procedure

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. Two operators conducted the experiment to study the bias between different operators. Each operator counted white specks on 20 sample lots on two rolls of fabric using both the white speck counter and manual counting. The whole process was repeated six times.

The manual (visual) counting, of white specks was performed using a magnifying lamp and a 1 in^2 template. The template is a 10.2 cm (4 in) high and 16.5 cm (6 ½ in) long black metal plate, and has a slit of 10.2 cm (4 in) wide and 0.635 cm (¼ in) high so that the number of white specks in 6.4516 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 10 test lots on each of the two fabric rolls. The entire measurement procedure was repeated six times.

The white speck counter, on the other hand, counted white specks in a 2 in^2 area. Ten different locations were selected at random within a test lot for a total of 20 in^2. The total number of white specks in 20 in^2 was compared with that from the manual counting method. The same procedure was used for 10 test lots on one of the fabric rolls. The whole process was repeated six times before the second roll was tested. The white speck counter was recalibrated once for each roll. The total number of white specks counted by two operators using two counting methods were compared using SAS procedures GLM and LSMEANS (SAS, 1990).

RESULTS AND DISCUSSION

Tables 1 and 2 show the average white speck counts of each lot in rolls MQ-294 and MQ-279 measured by two operators, Op 1 and Op 2, using the white speck counter and the manual counting methods. Each individual white speck count in the table is the average of six repetitions. Figures 3 and 4 show the same data graphically for rolls MQ-294 and MQ-279, respectively. The first two bars for each lot show the white speck counts using the

Table 1. Average white speck count of 10 lots in roll MQ-294, measured by two operators using the white speck counter and the manual counting methods.

		Lot number for roll MQ-294									
		1	4	5	6	10	11	12	16	17	18
WSC	Op 1	37.2	29.0	31.2	29.2	29.2	27.8	19.3	9.0	10.5	5.0
	Op 2	36.8	29.2	31.3	28.8	30.7	22.5	24.7	9.2	11.3	6.3
	Avg.	37.0	29.1	31.3	29.0	29.9	25.2	22.0	9.1	10.9	5.7
MAN	Op 1	29.7	17.0	21.7	22.7	20.5	18.0	15.0	10.3	9.6	6.3
	Op 2	41.7	21.3	20.7	21.8	17.5	14.5	18.7	10.0	8.6	8.0
	Avg.	35.7	19.2	21.2	22.3	19.0	16.3	16.9	10.2	9.1	7.2

Table 2. Average white speck count of 10 lots in roll MQ-279, measured by two operators using the white speck counter and the manual counting methods.

		Lot number for roll MQ-279									
		721	722	723	724	725	726	727	728	729	730
WSC	Op 1	48.5	54.8	50.5	45.0	61.3	60.3	53.2	65.7	58.3	52.3
	Op 2	52.7	57.5	55.8	52.5	64.8	64.2	58.7	62.3	57.2	53.8
	Avg.	50.6	56.2	53.2	48.8	63.1	62.3	56.0	64.0	57.8	53.1
MAN	Op 1	44.5	42.0	34.7	38.2	43.3	45.7	39.2	41.0	41.8	36.5
	Op 2	54.2	61.3	57.2	51.5	62.8	58.2	56.8	62.5	60.5	45.7
	Avg.	49.4	51.7	46.0	44.9	53.1	52.0	48.0	51.8	51.2	41.1

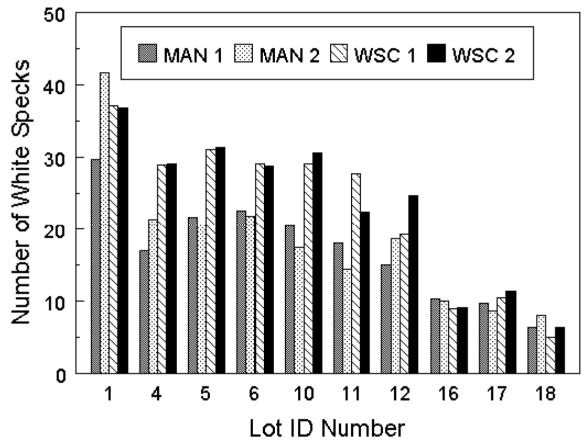

Fig. 3. Average number of white speck counts on roll MQ-294.

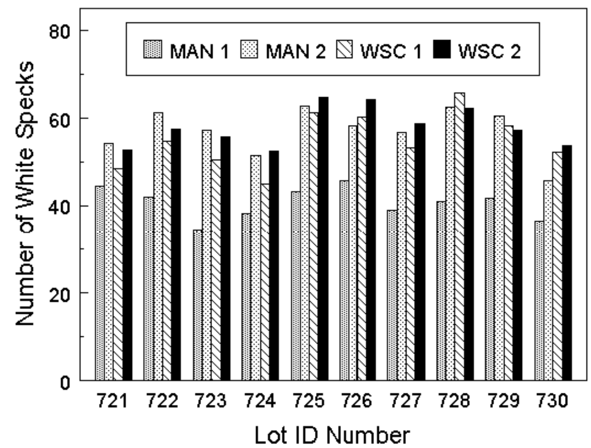

Fig. 4. Average number of white speck counts on roll MQ-279.

manual counting method and the third and fourth bars show the white speck counts using the white speck counter method.

As seen from these data, there are variations between counting methods and different operators. When the averages of two operators for each counting method were compared, the white speck counter generally overestimated the number of white specks relative to the manual counting method. The white speck counter method underestimated only two of the 20 lots tested and overestimated the rest of the lots. In terms of the differences in numbers of white specks, the average difference between two counting methods ranged from 1.5 to 12.3 specks. Statistical analysis also showed that there was a highly significant difference between the two counting methods. It was suggested that noise in the image may have been counted as white specks. Some of the difference may have come from the different image magnification between manual counting and the white speck counter. Despite the difference, the two operators with extensive experience in manually counting white specks expressed that the white speck counter performed adequately, and confirmed that the white speck counter counted what should have been counted as white specks in each image.

The manual counting method has larger variations between operators than the white speck counter (Fig. 3 and 4). The differences between the two operators using the white speck counter were much smaller than those using the manual counting method. For roll MQ-294, which has a relatively low number of white specks, the differences between the two operators ranged from 0.3 to 12.0 specks for manual counting, whereas the differences were between 0.1 and 5.4 specks using the white speck counter. For roll MQ-279, which has a higher number of white specks than MQ-294, the differences ranged from 9.2 to 22.5 specks for manual counting method, and from 1.1 to 7.5 specks for the white speck counter. Statistical analysis confirmed that there was a highly significant difference between two operators using manual counting, while there was no significant difference between two operators using the white speck counter. Therefore, it was concluded that the white speck counter performed more consistently and objectively than the manual counting method.

The variability between the operators was attributed to the high degree of subjectiveness of the manual counting of the white specks. Each operator was subject to eye stress and strain that came from the surrounding lighting and inspecting small specks through a magnifier. Each operator may also have a preconceived idea about the number of white specks within a lot of cloth. If one operator felt that a roll of cloth should be high in white speck number, then that operator may skew the count to achieve such a high number. For example, it was observed that operator 2 had a consistently higher average white speck count than operator 1 for all 10 lots within roll MQ-279. It was expected that the operators would have significant variations in manual count, but it was not expected for one operator to have all lot counts consistently higher than the other operator as seen in MQ-279. This shows the human subjectiveness in the manual counting method. Detailed discussion about the operators' performance and consistency among six replications can be found in Lambert (1997).

CONCLUSIONS

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 ambient light fluctuations, and automatically perform threshold and calibration. The white speck counter was designed to replace the tedious and subjective manual counting method. The performance of the white speck counter was compared with that of the traditional manual counting of white specks on knit fabrics in terms of accuracy, repeatability, and sensitivity to different operators. Conclusions drawn from this study are:

1. The white speck counter counts white specks faster and more efficiently than the manual counting method, although the white speck counter generally overestimates the number of white specks compared to the manual counting method.

2. There is a highly significant difference between operators using the manual counting method while there is no significant difference between operators using the white speck counter.

3. The white speck counter performs more consistently and objectively than technicians using the manual counting method.

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