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TEXTILE TECHNOLOGY

Expert and Novice Operator Comparison with Scanner-based Image Analysis for White Speck Detection on Dyed Yarn

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ABSTRACT

Current commercial fiber testing was not designed to measure or detect white specks in the small quantities that have been determined to be detrimental to the quality of dyed, finished products. In the absence of applicable fiber testing, the most logical step would be the development of counting methodologies, which would allow the accurate and repeatable quantification of white specks in a test medium that has significance to an end-product. Prior work indicated that dyed yarn was such a test medium, but the manual white speck reading process used was influenced by the limitations of human inspectors. There is a need for the application of scanner-based image analysis techniques and protocols to replace the human expert in the quantification of white specks on dyed yarn. One of the first challenges was describing a white speck from a human visual defect perspective in parameters that could be identified by image analysis counting software. This study undertook the task of creating an operational definition of a white speck confirmed by human observations that could be used to establish measurement parameters for a scanner-based image analysis procedure for counting white specks. Results demonstrated that by using scanned images of dyed yarn, in conjunction with counting software, it was possible to develop an operational definition of a white speck in terms of pixel area and gray scale level that relates to human observations.

Due to the lack of secondary cell wall development, immature fibers are weaker, less rigid, and have a lower density than mature fibers. These factors result in a higher propensity for immature fibers than for mature fibers to form neps (Hebert et al., 1988). In an un-dyed state, entangled fiber clusters are generically classified as neps. In most cases, fiber neps consist of at least five fibers with an average of 16 or more fibers (Herbert et al., 1988). It is only after the application of dye, when some neps remain undyed, that the more specific classification of "white speck" is used (Herbert et al., 1988).

High volume instrument (HVI) fiber testing, based on average fiber properties, was not designed to measure or detect the presence of immature fibers in the small quantities that have been determined to be detrimental to the quality of dyed finished goods (Zellweger Uster, 1999). It has been estimated that even in fabric with severe white speck contamination the percentage of white speck fibers (by weight) is most likely less than 0.10% of the total fibers (Watson, 1989). These amounts would be too small to have significant effects on the average fiber properties, as measured by current commercial instruments, but are substantial enough to decrease the commercial value of the fiber to the end-user (Goynes et al., 1996).

Human experts have proven to be reliable and consistent for counting white specks on dyed yarn (Simonton et al., 2001). The problem with using humans is in the availability of expert operators to perform the counting task. Prior work highlighted that not all humans are capable of achieving expert operator status for the counting of white specks, which limits the pool of potential operators (Simonton et al., 2001; 2003). The current research established an operational definition of a white speck that could link visual results obtained by expert and novice operators with those obtained through image analysis. It was hypothesized that white specks observed on the surface of dyed yarn by humans could be operationally defined by size and gray scale level using scanner-based image analysis techniques and protocols.

MATERIALS AND METHODS

This research was divided into the following segments: (1) creation of dyed sample yarns and boards, (2) digitizing sample boards loaded with

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dyed yarn, (3) image analysis, (4) expert operator identification of white specks, (5) novice operator identification of white specks, and (6) analysis of the results. An explanation of each of the research segments is provided below. Procedures and protocols developed in prior work were used for counting white specks by humans in this research (Simonton et al., 2001; 2003).

Sample yarn. A 24.6/1 Tex ring spun yarn with a 4.2 twist multiple (812 turns per meter) were created from a group of cotton fiber samples taken from commercial bales of cotton. The yarns were intended to represent a test group with the potential of having a very low to very high range of white speck content. The processing flow diagram for the sample cottons is provided in Figure 1.

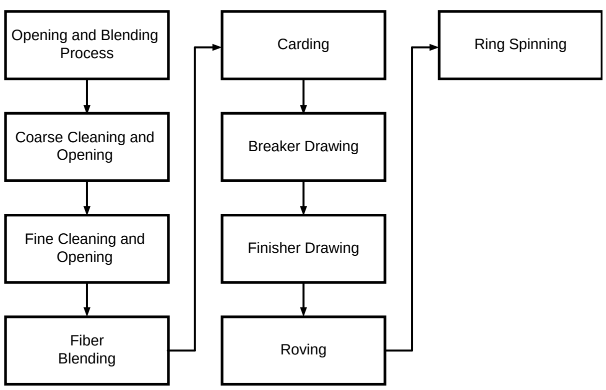

Figure 1. Flow diagram for textiles processed in these experiments.

Sample dyeing. A Chavis Model 44 yarn winder (Chavis Textile Manufacturing, Inc.; Gastonia, NC) was used to place the samples onto stainless steel dye tubes for dyeing. After winding, these samples were package dyed using a Morton Package Dye Machine Model 77-132-1 (Gaston County Dyeing Machine Co.; Gastonia, NC). The textile industry has long recognized reactive dyes as one of the preferred dye families for dyeing cotton due to their good color fastness to light and to washing along with their superior coverage capabilities (Trotman, 1975). The dye used for the yarn was a mixture of three commercial reactive dyes; 0.016% Drimarine Yellow K-2R Reactive Yellow 125 (Clariant Corp.; Charlotte, NC), 3.6% Intracon Brilliant Blue VS-RW Reactive Blue 19 (Crompton and Knowles; Reading, PA), and 2.7% Intracon Navy Blue VS-HR Reactive Blue 89 (Crompton and Knowles). This combination resulted in a navy blue color that provided the dark shade required for revealing white speck contamination.

Yarn board fabrication. After the dyeing process, an Alfred Sutter yarn board winder (Alfred Sutter; New York, NY) was used to wind samples onto 178-mm wide by 279-mm long by 3.2-mm thick, black, rigid paper yarn boards. Of the 178 mm available on the board, only 135 mm was used in the winding process to achieve the desired sample length. Each sample was used to fabricate five yarn boards containing a minimum of 200 m of yarn per board or approximately 26.8 wraps per cm. Each board created was labeled with an "A" and "B" side. The "A" and "B" designations were arbitrary designations for the purpose of preventing the operators from reading the same side twice. A total of 10 boards were fabricated for the white speck identification process for each bale sample.

Digitized board images. In other image analysis processes not directly related to yarn white specks, flat bed scanners have been used to acquire images. It was noted that for samples that were within the size limitations of the scanner bed and with a thickness that allowed the lid to close over the sample, flat bed scanners worked well (Shiau et al., 2000). The scanner parameters were set to minimize or totally disable several optional features contained in the scanner software, such as auto sharpening and digital interpolation, which were designed to optimize images. These features were not designed for this type of work and in some cases inhibited the process.

Care must be taken when using flat bed scanners to create images for measurement software. As part of the protocol the scanner was validated with samples of known white speck content before each scanning session. A cold scanner provided images that possessed different white speck levels than those obtained when the scanner had been stabilized. With this knowledge, it was possible to establish test protocols that provided stable and consistent images for the counting software. It was also discovered that the time between scans was critical. For this reason, the protocol included an allowable time range between scans for the operator to work within.

Prior work indicated that gray scale images would work well with image analysis software for this particular type of application (Stojanovic et al., 2001). Gray scale consists of 256 shade increments with 0 being black and 256 white. The 256 gray scale shades provided sufficient increments to make fine distinctions between target objects and backgrounds. The result of the scan was a two-dimensional map of pixels with each pixel holding a gray scale intensity measurement corresponding to the reflectance or the transmittance of the object at the physical location represented by that particular pixel (Gann, 1999).

As the result of numerous preliminary trials, the sample boards were digitized with a 118 dots per centimeter (300 dpi) resolution in gray scale (256) with a Hewlett-Packard Scan Jet Model 7400c flat bed scanner (Palo Alto; CA) attached to a Dell Model 530 computer (Round Rock, TX) equipped with a 1.7 GHz Xeon processor. Image files created from the process were stored in the bitmap (bmp) format. Bitmap files work well in image analysis applications when using images taken from scanners (Shiau et al., 2000).

Image analysis. The software package, Counting Apparatus for Trash and Impurities (CATI, version 6, CIRAD Laboratories; Montpellier, France), was used for white speck counting. The software package has the features required for determining the area occupied and the average gray scale level of objects being identified. In a simplified explanation, CATI scans each pixel row by row and compares the gray scale value contained in each pixel with the predetermined gray scale measurement parameter. If the actual value is greater than the minimum parameter value, the software identifies it as an "open object". The software then moves to the next pixel and repeats the process. As the software moves down the image it retains the "x" and "y" coordinates for each pixel that exceeded the minimum gray scale parameter. When an open object of interest is surrounded or encapsulated by background pixels, it becomes a "closed object". Once it has been classified as a closed object, the software applies operator controlled minimum size (pixel area) selection parameters. If these parameters are satisfied, then the closed object will be classified as an object of interest (white speck).

The CATI system provided a text printout of "x" and "y" grid coordinates for each object identified as a white speck. The grid coordinates were based on 118 dots per centimeter resolution. For example, a grid coordinate of x = 850 and y = 645 for an image scanned at 118 dots per centimeter (300 dpi) would indicate the object of interest would be located 7.2 cm in the "x" direction and 5.5 cm in the "y" direction. This type of information made it possible to visually locate white specks identified by the CATI software.

For this operation, the predetermined CATI gray scale parameter was set at 74. When considering this parameter, any pixel that had a value of 74 or above was considered an object of interest from a gray scale perspective. Gray scale 74 was selected because preliminary testing indicated that this level was the limit of the expert operator's ability to differentiate a white speck from background.

After the object of interest meets the gray scale selection criteria, size became the selection criterion. The minimum size parameters were set at six pixels of surface area at 118 dpc (300 dpi) of resolution. Six pixels of area were used because test results indicated that 6 pixels was the limit of the expert operator's accuracy.

Human verification. A sample group of yarn boards selected for the trials were each placed into separate clear plastic sleeves. The plastic sleeves were secured to the yarn boards with heavy-duty clips to prevent slippage. Once secured, a series of alignment marks were added to the clear plastic sheets to verify the alignment when the operator opened and closed the sleeves during the reading process. This configuration also allowed the operator to read both sides of the yarn board without changing the clear plastic cover sheet.

Expert operators. Two expert operators, working simultaneously, identified white specks on the ten sample boards. Using a red permanent marker, the expert operators circled the white specks they observed on the clear plastic sleeve. Once the expert operators had completed the detailed reading of all boards, the plastic sleeves containing the circles were removed. Each of the circles on the sheet was numbered sequentially. The expert operators then began the task of matching the physical coordinates of the circles with the grid coordinates given by CATI. Once this had been completed, size and gray scale level was assigned to the circled white specks based on CATI information. The process was intended to verify that the white specks identified by CATI also existed as a human visual defect. The clear plastic sheets created by the expert operators during this phase were used as master templates for evaluation by the novice operators.

Novice operators. It was not only important to confirm the existence of a white speck by expert operators, but it was also important to understand what a group of novice operators would see when examining some of the same boards. A trial was developed with a group of 11 novice operators who possessed varying degrees of experience related to the cotton industry.

Each novice operator was presented a group of four yarn boards taken from the set used previously in the expert operator work. Each board was equipped with the clear plastic sheet as described previously. The boards were intended to represent a group of boards with different levels of visible white specks as determined by counts collected by the expert operators.

The sample boards were placed inside of a Veri-Vide light cabinet (Equitex; West Yorkshire, UK) to provide a consistent source of lighting. From a training script, a designated expert operator first read the definition of a white speck to be used. For this work, a white speck was defined as surface clusters of fibers in dyed textile products that are noticeably lighter in color than the body of fibers adjacent to them. Based on this definition, each novice operator was asked to point out to the expert operator what he/she considered to be white specks on the first of the four yarn boards. The expert operator also demonstrated the technique used for circling the observed white specks on the clear plastic cover sheet. After completion of the first board, it was set aside and the sample set of three yarn boards were presented the novice operator. From this point, the expert operator did not supply feedback or comments.

Using the master templates as overlays, the researchers were able to identify the white specks circled by the novice operators. When the white speck identified by a novice operator matched one on the master template, it was assigned the master template white speck identification number. The identification number was then used to acquire the size and gray scale level of the identified white speck.

RESULTS AND DISCUSSION

Expert operators and CATI comparison. Using a minimum area of six pixels and a minimum gray scale of 74 as measurement parameters, CATI identified 1,348 objects on the 20 board sides processed. The expert operators confirmed the visual existence of 1,099 white specks, or 81.5% of the white specks identified by CATI. Figure 2 contains the frequency distribution of the size of the white specks observed by the expert operators. Figure 3 contains the same information for gray scale.

It is important to evaluate the relationship between size and gray scale reading to understand the discrepancy between the human and CATI white speck counts. The 249 objects identified by CATI but not identified by the expert operators were examined. The main difference occurs in the smaller pixel ranges and lower gray scale readings. As white speck pixel area decreased, operator discrepancy with CATI increased (Fig. 4). There was also more discrepancy between the operator and CATI as gray scale decreased (Fig. 5). These results indicate that the CATI system with its current parameters is more sensitive to the smaller, darker white specks than the expert operators. A more in depth examination revealed that 65.46% of the objects detected by CATI that were not detected by the experts were nine pixels (0.065mm) or fewer in size, and 65.06% had a gray scale of 80 or less.

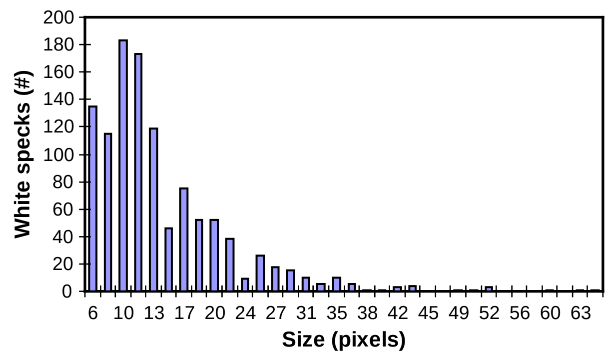

Figure 2. Distribution by pixel size of CATI white specks that were confirmed by expert operators.

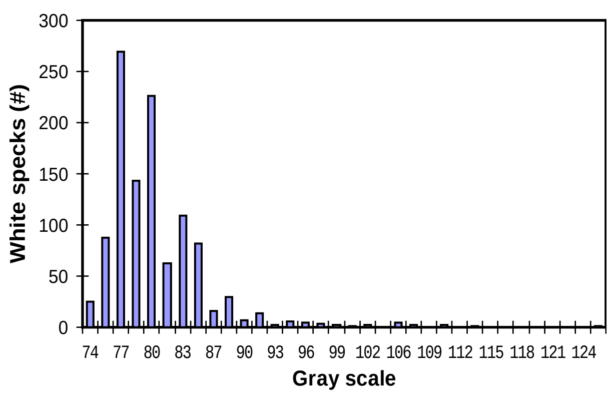

Figure 3. Distribution by gray scale of CATI white specks that were confirmed by expert operators.

To simplify the size comparisons, the area of a white speck was stated in the number of pixels occupied when scanned at 118 dots per centimeter with a 74 gray scale setting. Within these parameters, 87.90% of the white specks observed were less than or equal to 21 pixels (0.151 mm^2) in total area. Approximately 47.8% of the white specks observed were ten pixels (0.072 mm^2) in area or less. A total of 12.2 % and 10.5% of the observed white specks were identified in the seven and six pixel range, respectively. The six (0.043 mm^2) and seven (0.050 mm^2) pixel white specks comprised 22.7% of the total white specks observed by the expert operators.

A total of 92.7% of the white specks observed by the expert operators had a gray scale 86 or less. The lowest gray scale value of 74 accounted for 2.3% of the white specks observed with gray scale 75 accounting for 8.0% of the white specks. The largest single gray scale increment was 78, which contained 13.0% of the white specks.

The results indicated that the CATI system is more discriminating at the lower end of the gray scale and size range than the expert operators. This could indicate that the CATI set-up parameters used in this research are approaching the lower limits of the expert operator's internal definition of a visual white speck defect.

Novice operators. The eleven novice operators generated a total of 1,553 data points. These results were broken down into size and gray scale components and presented as a detection rate percentage. The results show a direct positive relationship between detection rate and the size of the white specks (Fig. 6). For the novice operators the detection rate declined as the white speck decreased in size. When white specks were 19 pixels (0.136 mm^2) or more in size, the novice operator detection rates were high (>78%). In contrast, when the white specks occupied 9 pixels (0.065 mm^2) or fewer, only a small percentage of the eleven novice operators were able to detect them (<14%).

The effect of gray scale reading was not as obvious as the size component on the ability of novice operators to detect specks. Without the size component, gray scale was not a consistent indicator of detection rate (Fig. 7). It is only when both components are examined together that a clearer view of the relationship between size and gray scale appears.

Linear trends for gray scale value groupings with pixel count on the "x" axis and the number of novice operators that detected the white speck on the "y" axis were plotted (Fig. 8). Four gray scale value groupings were plotted. The graph illustrates that the detection rate improved as the white specks became lighter in shade and larger in size with the lowest detection rate for white specks in the lower end of the gray scale (74 to76) that are fewer than ten (0.072 mm^2) pixels in total area. Linear trends were plotted for the size component with grayscale on "x" axis and the number of novice operators that detected the white speck on the "y" axis (Fig. 9). The plot shows detection rate for the novice operators was low for all white specks between six (0.043 mm^2) and eleven pixels (0.079 mm^2) of total area regardless of the gray scale level. The detection rate was improved for the novice operators when the white specks were greater than eleven pixels in total area (0.079 mm^2).

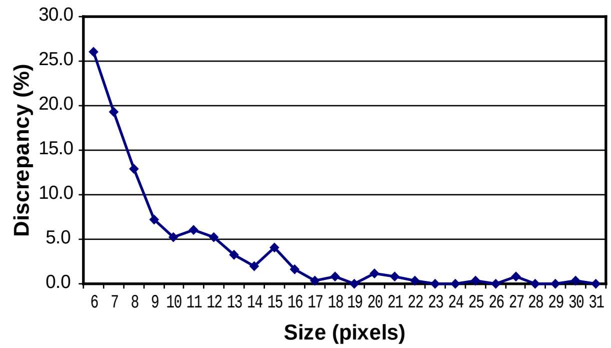

Figure 4. Discrepancy (%) between CATI and expert operators in detecting white specks based on size.

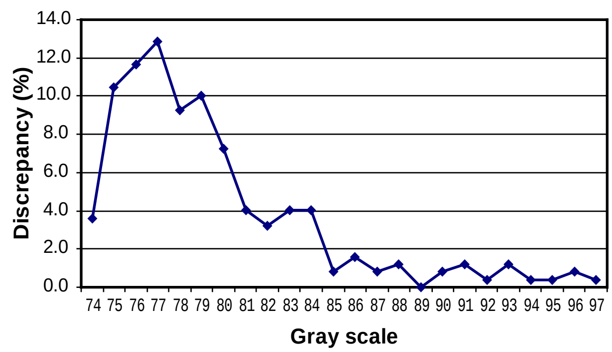

Figure 5. Discrepancy (%) between CATI and expert operators in detecting white specks based on gray scale.

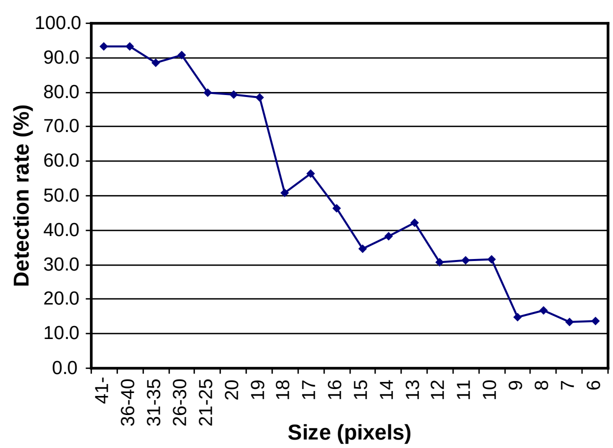

Figure 6. Detection rate (%) of white specks based on size by novice operators.

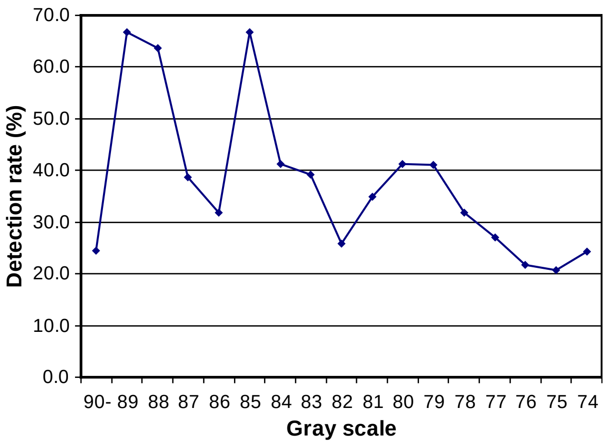

Figure 7. Detection rate (%) of white specks based on gray scale by novice operators.

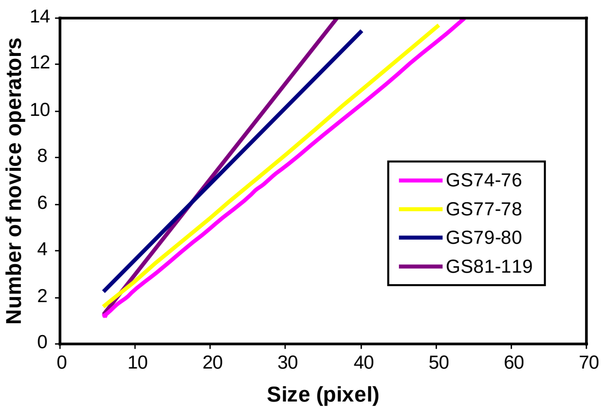

Figure 8. The effect of size at various gray scale levels (GS) on the detection of white specks by novice operators.

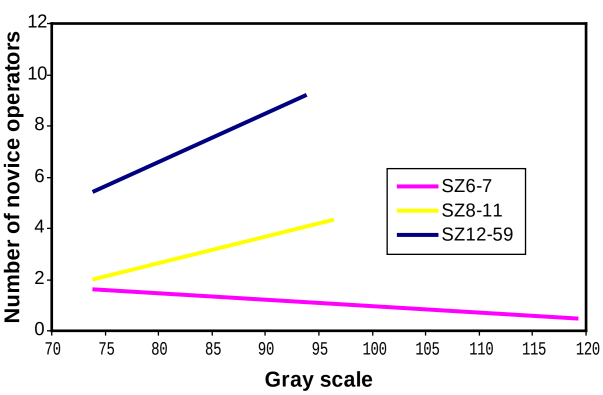

Figure 9. The effect of gray scale at various size levels (SZ) on the detection of white specks by novice operators.

Expert and novice operator comparison. The comparison of expert and novice operators is interesting from several perspectives. The plot of the detection rate of the two groups illustrates the difference in detection rate when size is the determining factor (Fig. 10). The expert operators demonstrated proficiency at the lower pixel areas, while the proficiency level of the novice operators only improved when higher pixel densities were reached.

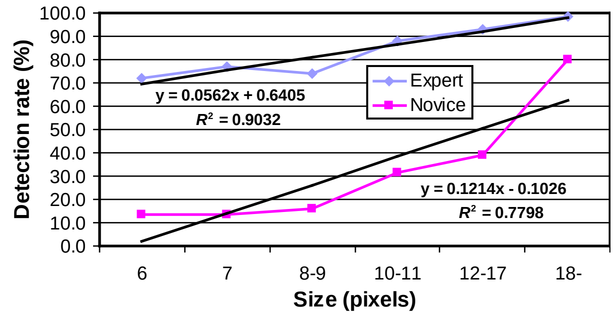

Figure 10. Comparison of the detection rate of white specks based on area for expert and novice operators.

Gray scale levels followed the trends demonstrated by pixel area for both groups of operators (Fig. 11). Expert operators were able to detect white specks even at the lower, darker end of the gray scale, while their novice counter parts detection rate was low regardless of the gray scale reading.

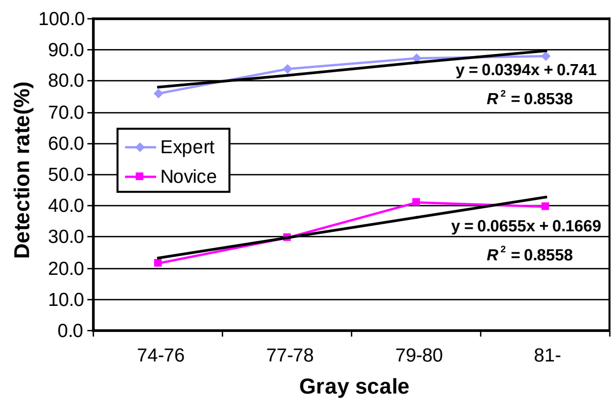

Figure 11. Comparison of the detection rate of white specks based on gray scale for expert and novice operators.

Cost of quality. Since white specks are human visual defects, it is important to address the link between what a human detects visually and their internal definition of the white speck quality issue. Beasley implied that there was not a universal definition of quality but rather operational definitions specific to the end user and organization when he stated, "quality is not as much defined as understood" (Beasley, 2001 pg. 12). This opinion was supported by Deming's (1994) belief that quality is always customer defined. If quality is defined by a customer, then it becomes an economic issue. Beasley (2001) supported this point by suggesting that quality exists in an environment that has value for it. This point poses the question that if white specks have not been operationally defined, then how can an acceptable or unacceptable level be established by the market place. This is a major cost of quality issue for the entire cotton industry.

As demonstrated in this work, there is a large discrepancy between white specks observed by experts and those observed by novice operators. When designing a system for white speck detection and quantification, a decision has to be made on the type of operator that will be used. This decision will determine which and how many white specks are detected. It also makes defining the qualifications for becoming a novice or expert operator an issue. At what point does an operator move from novice to expert? These variables do not allow an operational definition using human operators alone to be formed since the type and experience level of the operator affects the count obtained.

If an image analysis system is developed based on novice operator observations, then there will be a higher probability of a Type II error in which white specks are not detected by the image analysis process but are detected by humans in the finished product. If expert operator observations are used to establish image analysis baselines, then Type I errors are possible, where the image analysis process detects white specks that have a low probability of being detected in the finished product by humans. This difference in detection rate between these two groups creates a cost of quality issue. Both Type I and II errors have costs associated with them, from an actual cost to a perceived cost associated with reputation in the market place. Without a clear standardized white speck operational definition, the type of error that should be designed for by the industry is unknown.

CONCLUSION

These results demonstrated that when using the described protocols and scanner-based image analysis techniques, white specks on dyed yarn can be characterized by area occupied and gray scale level. The characterization furnishes an operational definition of a white speck, which in turn also provides the link between human white speck observations and white specks identified by the counting software.

The research also highlights the need for determining at what size and gray scale a white speck becomes important to a human operator and whether or not those parameters should come from expert or novice operators. By having this knowledge, prescriptive steps could be focused on the size of white specks that are detrimental to finish product quality, while having minimum affects on other critical fiber, yarn, and fabric properties.

ACKNOWLEDGEMENTS

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REFERENCES

Beasley, J. 2001. Understanding quality. Forum on the metaphysics of quality. Available online at www.moq.org/forum/johnbeasley4.html (verified 30 Nov. 2005).

Deming, W.E. 1994. The new economics, 2^{nd} ed. Massachusetts Institute of Technology, Cambridge, MA.

Gann, R. 1999. Desktop scanners: image quality evaluation. Prentice Hall, Upper Saddle River, NJ.

Goynes, W.R., Bel-Berger, P.D., and Von Hoven T.M. 1996. Microscopic tracking of white-speck defects from bale to fabric. p. 1292-1294. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Hebert, J.J., Boylston, E.K., and Thibodeau, D.P. 1988. Anatomy of a nep. Textile Res. J. 58 (7): 380-382.

Shiau, Y., Tsai, I., and Lin, C. 2000. Classifying web defects with a back-propagation neural network by color image processing. Textile Res. J. 70 (7): 633-640.

Simonton, J.L., Hequet, E.F., and Beruvides, M.G. 2001. A pilot study: using dyed cotton yarn for the quantification of white specks. p. 1317-1319. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Simonton, J.L., Beruvides, M.G., Altintas, P.Z., Kang, K. 2003. Effect of textile treatments on white speck counts in dyed yarn. p.1996-2002. *In* Proc. Beltwide Cotton Conf., Atlanta, GA. 6-10 Jan. 2003. Natl. Cotton Counc. Am., Memphis, TN.

Stojanovic, R., Mitropulos, P., Koulamas, C., Karayiannis, Y., Koubias, S., and Papadopoulos, G. 2001. Real-time vision-based system for textile fabric inspection. Real-Time Imaging 7: 507-518.

Trotman, E. R. 1975. Dyeing and chemical technology of textile fibres. 5th ed. Charles Griffin & Co., LTD, London.

Watson, M.D. 1989. Difficulties in forecasting fabric white spots from fiber maturity. p. 130-135. *In* Proc 2nd Eng. Fiber Selection Conf., Memphis, TN. 20-21 June, 1989. Cotton Inc., Raleigh, NC.

Zellweger Uster. 1999. Description of all quality parameters measured by Zellweger Uster. Available online at http://www.uster.com/en/index_4.asp (verified 27 Apr. 2004).