Objective Assessment of Pilling of Nonwoven Fabrics Using the Two Dimensional Discrete Wavelet Transform

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Abstract - Fabric pilling is a serious problem for the apparel industry, causing an unsightly appearance and premature wear. Woolen products are particularly prone to pilling. Recently, a process for production of woolen nonwoven apparel fabrics has been commercialized in Australia, and may lead to new markets for Australian wool. However, the success of such nonwoven fabrics will partly rely on their propensity to pill. A key element in the control of fabric pilling is the evaluation of resistance to pilling by testing. Resistance to pilling is normally tested in the laboratory by processes that simulate accelerated wear, followed by a manual assessment of the degree of pilling by an expert based on a visual comparison of the sample to a set of test images. To bring more objectivity into the pilling rating process, a number of automated systems based on image analysis have been developed. The authors previously proposed a new method of image analysis based on the two-dimensional discrete wavelet transform to objectively measure the pilling intensity for woven fabrics. This paper presents preliminary work in extending this method to nonwoven fabrics.

Keywords: pilling, nonwoven, wavelet analysis

I. INTRODUCTION

Pilling is the formation of small tangles of fibers or balls on the surface of a fabric during washing, testing or in wear. The 'pills' on a fabric surface make the fabric very unsightly and such fabrics are rejected by discerning consumers. Pilling has been a serious problem for the apparel industry, which has traditionally been dominated by knitted and woven fabrics. The rapid development of nonwoven apparels in recent years has added a new dimension to the perennial problem of fabric pilling, and no fundamental research has been carried out on the pilling of nonwoven fibrous materials.

A nonwoven fabric is a consolidated thin web of fibers. The nonwoven process is a relatively simple fiber-to-fabric process, compared to the lengthy and expensive fiber-yarn-fabric process used for producing traditional woven and knitted fabrics. Nonwoven materials differ from woven and knitted materials in structure and performance. But they have many important applications, including hygiene absorbents, medical textiles, filters, geotextiles, natural fiber products, composite materials, vehicle textiles, building materials, cushioning, carpet and insulation. These applications are predominately technical textiles manufactured from synthetic fibers [DAV, 03].

Australia produces the best quality wool: merino wool. Worldwide, over 70% of the wool for apparel use comes from Australia. Total wool production in 2000-01 was valued at $A2.5b - around 7% of Australia's agricultural output [AUS, 03c]. However, conventional wool fabrics have a relatively high tendency to pill, which has contributed to the declining share of wool in the world fiber market [AUS, 03a].

Very recently, a process for the production of woolen nonwoven apparel fabrics has been commercialized in Australia. The nonwoven process is 30 percent cheaper and 30 times faster than traditional wool fabrics by eliminating the conventional spinning and weaving (or knitting) stages [AUS, 03b]. The entry of wool into nonwoven applications will create new markets for Australian wool as a competitor for nonwoven fabrics. However, the success of such nonwoven apparels will, to a certain extent, depend upon their pilling propensity. To date, virtually no research has been published on the mechanism, measurement, prediction and control of pilling in nonwoven wool fabrics, and this issue will be crucial in the success of wool in many nonwoven textile applications.

The development of practical and commercial nonwoven woolen textiles is a significant innovation, creating "fabrics with unique properties that cannot be achieved by traditional knitting or weaving, opening up a whole new range of market opportunities for Merino wool" [WOO, 03]. The ultimate market for Australian nonwoven woolen products is international, and the commercial export of these products is a key strategy in their development [DOC, 03]. For the potential of nonwoven woolen fabrics, and apparels in particular, to be realized, the perennial problem of woolen pilling will need to be overcome [THE, 00]. Australian Wool Innovation (AWI) has identified that removal of pilling is a key message from consumers, retailers and designers [AUS, 02]. Reduction of pilling is also listed as its top priority [AUS, 03a].

Fabric pilling is a serious problem for the apparel industry [UKP, 98]. Pills cause an unsightly appearance and can cause premature wear [RAM, 93]. A key element in the control of fabric pilling is the evaluation of resistance to pilling by testing. Resistance to pilling is normally tested in the laboratory by processes that simulate accelerated wear, followed by a manual assessment of the degree of pilling by an expert based on a visual comparison of the sample to a set of test images [ABR, 98]. A frequent complaint about the manual/visual evaluation method is the inconsistency and inaccuracy of the rating results [XU, 97]. In an attempt to bring more objectivity into the pilling rating process, a number of automated systems based on image analysis have been developed and described in the literature [ABR, 98, AMI, 94, HSI, 98, SIR, 00, XU, 97]. All of these existing methods either employ expensive and complicated equipment, such as laser triangulation imaging [RAM, 93, SIR, 00], and/or employ complex image processing algorithms that involve multiple stages [ABR, 98, XU, 97].

II. OBJECTIVE ASSESSMENT OF PILLING OF WOVEN FABRICS

The authors have pioneered an innovative, simpler method of objective pilling rating of woven fabrics based on quantitatively relating the standard deviation of the two-dimensional discrete wavelet transform (2DDWT) detail coefficients to the intensity of woven fabric pilling. Fig. 1 shows: a) three of the five standard pilling evaluation test images from the James H. Heal & Company Limited '1840 double jersey' set, including the supplier rated intensity of pilling (5 = unpilled, 3 = moderately pilled, 1 = heavily pilled); b) the distribution of the 2DDWT horizontal detail coefficients at four levels of analysis using the Haar wavelet; and c) the plot of test image pilling intensity versus the standard deviation of the distribution of the 2DDWT level four detail coefficients.

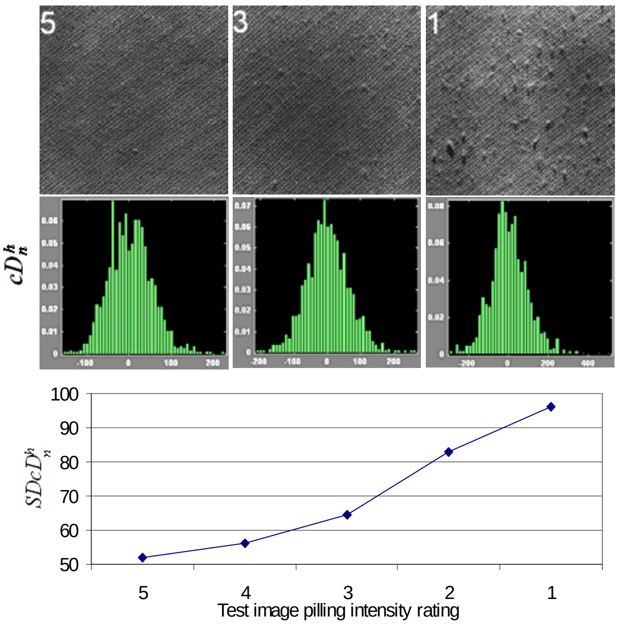

Fig. 1. (top) James H. Heal '1840 double jersey' fabric test images, (centre) Distribution of 2DDWT detail coefficients, and (bottom) Standard deviation of wavelet detail coefficients

The authors have developed a heuristic method for selecting the optimal wavelet analysis parameters [PAL, 03b], and established that the method is robust to translation of the sample under test (see Fig. 2) and to variations in the illumination of the sample under test (see Fig. 3) [PAL, 04]. The application of wavelet analysis to the automated detection of fabric flaws is an emerging field [HU, 00, LAT, 01, LI, 02, SAR, 99, WEN, 01], however, the prior and current work by the authors is significant as it is the first appearance in the literature of the application of wavelet analysis to the problem of objective rating of pilling intensity. The underlying technique, wavelet analysis, offers novel approaches for tackling the objective assessment of pilling using image analysis for nonwovens as well.

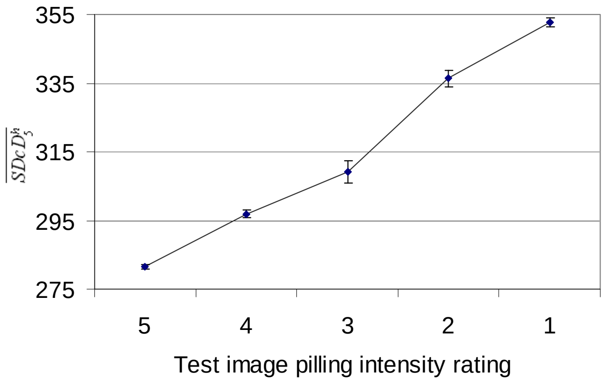

Fig. 2. Mean of standard deviation of wavelet detail coefficients and 90 % confidence intervals for image translations based on 1840 test images

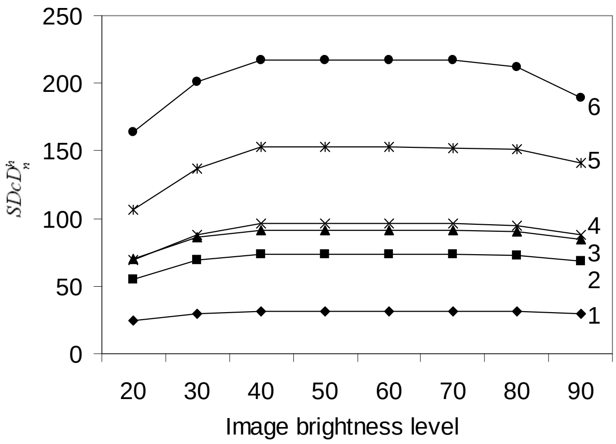

Fig. 3. Standard deviation of wavelet detail coefficients at first six analysis levels for variation in image brightness of 1840 test image pilling intensity level 1

III. OBJECTIVE ASSESSMENT OF PILLING OF NONWOVEN FABRICS

Resistance to pilling is normally tested by simulated accelerated wear, followed by a manual assessment of the degree of pilling based on a visual comparison of the sample to a set of test images. There exists one set of international standard test images based on nonwoven wool fabric, the Woolmark 'SM50 Blanket' set. This image set provides four representative samples for each of five levels of pilling intensity Fig. 4 shows one of the representative samples for three of the five standard pilling evaluation test images from the Woolmark 'SM50 Blanket' set, including the supplier rated intensity of pilling (5 = unpilled, 3 = moderately pilled, 1 = heavily pilled). This test image set will be used as the basis for developing a wavelet-based image analysis technique for objectively assessing pilling intensity for nonwoven wool fabrics.

The two-dimensional discrete wavelet transform process produces two complimentary analysis components – detail coefficients and approximation coefficients. The detail coefficients represent the high spatial frequency components of the image, and are the basis used by the authors to characterize the impact of pilling on the periodic structure (fabric knit or weave) present in woven fabrics [PAL, 03a]. For nonwoven fabrics, the authors propose that the random/aperiodic structure of the fabric can be characterized by the wavelet approximation coefficients, which represent the low spatial frequency components of the image. The authors propose that there will be a wavelet analysis scale that will distinguish between the underlying random nonwoven structure and the presence of larger pill structures on the fabric sample, and, that the distribution of wavelet approximation coefficients at that analysis scale will provide a quantitative measure of pilling intensity. This proposition will be verified experimentally.

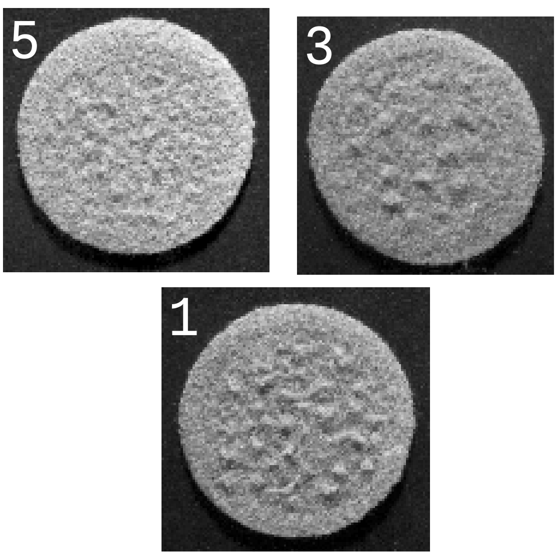

Fig. 4. Representative samples of The Woolmark Corporation 'SM50 Blanket' fabric pilling test images with supplier rated pilling intensity

The Woolmark 'SM50 Blanket' set of standard pilling images presents four examples of each of the five levels of pilling intensity. These 20 images were scanned at 600 dots per inch and cropped of edge markings. While the author's previous work with image analysis of woven fabrics based on wavelet detail coefficients has been shown to be robust to variations in image brightness, there are many image processing applications that are sensitive to image brightness variations [GHA, 02]. In this instance, we propose to use the wavelet approximation coefficients as the basis for analysis, however, as the approximation coefficients represent low frequency information in the image, they will be sensitive to variations in image brightness [MAN, 99]. Image pixel value histogram equalization is a useful method for putting images in a consistent format prior to comparison [CAS, 96], and is reported in wavelet [MOJ, 97] and other [SRI, 01] image analysis applications as a technique for dealing with variations in image brightness. The 20 images where pixel value histogram equalized.

For each of these 20 standard images, four additional images were synthesized by cropping one edge of the standard image by approximately 15 percent. This produced 100 images in total; 20 for each pilling intensity. For each of the 100 images, the standard deviation of the distribution of the approximation coefficients ($SDcA_n$) at various analysis scales, based on analysis using the Haar wavelet, was computed using the Matlab Wavelet Toolbox [THE, 04]. Using the mean value of $\overline{SDcA_n}$ obtained for the 20 test images at each level of pilling intensity, it was found that 2DDWT analysis at scale five produced a monotonic relationship between pilling intensity and $\overline{SDcA_5}$. Fig. 5 presents the mean value and 90 percent confidence intervals for $\overline{SDcA_5}$ (standard deviation of the distribution of wavelet approximation coefficients for level 5 analysis) for each pilling intensity.

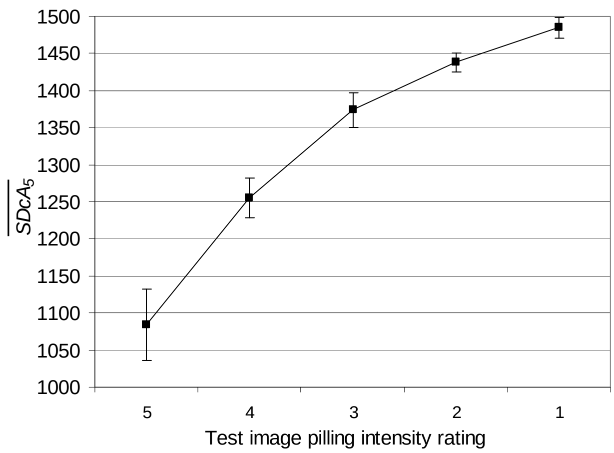

Fig. 5. Mean of standard deviation of level 5 wavelet approximation coefficients and 90 % confidence intervals for image translations based on SM50 Blanket images

It is proposed that it is possible to apply this image analysis method to a set of reference fabric pilling samples to develop a calibrated characteristic curve that relates pilling intensity to $SDcA_n$ obtained by analysis of a fabric test sample. In this way it is possible to perform an evaluation of pilling intensity that is analogous to the visual comparison method but, once calibrated for a given fabric type and test environment, will yield an objective measure without human interpretation.

IV. CONCLUSIONS

Based on using the Woolmark 'SM50 Blanket' standard pilling test images for nonwoven fabric and analogous concepts from the author's prior work, the feasibility of a new analysis technique to relate the standard deviation of the distribution of 2DDWT approximation coefficients with pilling intensity of nonwoven fabrics was demonstrated. Planned future work will investigate methods for determining the optimal analysis wavelet and analysis scale for a particular type of nonwoven fabric, and, evaluating the robustness of the analysis method.

V. ACKNOWLEDGEMENTS

The standard pilling test series images in Fig. 1 are the copyright property of James H. Heal & Company Limited and reproduced with their permission. The standard pilling test series images in Fig. 4 are the copyright property of The Woolmark Company and reproduced with their permission.

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