Texture Retention After Fabric-to-Fabric Abrasion

Ö. B. BERKALP,[1] B. POURDEYHIMI,[2] A. SEYAM, AND R. HOLMES

Nonwovens Cooperative Research Center, North Carolina State University, Raleigh, North Carolina 27695, U.S.A.

ABSTRACT

Changes in appearance brought about by mechanical abrasion may be evaluated with respect to changes in image texture properties, *e.g.*, periodicity. This paper discusses the application of gray-scale image analysis to texture periodicity measurements in fabrics. The techniques described are appropriate for "ordered" textures with relatively well defined features such as the Miratec® class of fabrics. Our samples consist of three sets, a woven twill, a Miratec (nonwoven) twill, and a loosely bonded herringbone hydroentangled nonwoven. In general, our data show that mechanical wear may result in a decrease in texture definition and a tendency toward randomness. The Miratec fabric shows that at the same level of wear, the structure retains its appearance and exhibits no loss of texture.

Tactile (hand) and appearance properties are very important in all classes of fabrics. The characteristics of textile fabrics in general, and of technical textiles in particular, depend on their geometry and surface contours. These are determined in a complex manner by the surface structure of the fibers and the yarn and fabric construction [4]. Appearance retention is directly related to the longevity and serviceability of fabrics. A fabric may lose its aesthetic appeal due to wear, which is a combined effect of several factors like abrasion, repeated laundering, application of forces in dry and wet states, etc., arising from everyday use and service. Surface abrasion is considered perhaps the most important of these factors, and so it has become routine in fabric testing.

Surface texture, and thus fabric appearance, is usually evaluated subjectively by a panel, following the procedures set forth in a number of standardized methods [1, 2]. But because of their subjective nature, these methods are characterized by poor accuracy.

The term "texture" originates from the Latin word "textura," which means "to weave." Thus, texture generally refers to repetition of basic texture elements called texels. A texel contains several pixels, whose placement can be periodic, quasi-periodic, or random. Natural textures are generally random, whereas artificial textures are often deterministic or periodic.

In periodic assemblies, the placement of the objects (texels in the case of textured surfaces) determines the appearance. Texture may be coarse, fine, smooth, granulated, rippled, regular, irregular, or linear [5, 7]. These properties refer to the spacing of the units, or what we would regard as the texture period. Additionally, the degree of exactness of the placement determines the degree of order. If one considers the texture in the Fourier space, then the period refers to the spacing and the power refers to the strength of the degree of order within the texture.

We consider textures as a continuum between two extremes. At one end is the deterministic texture, which has a regular pattern. Here, a texture is defined by elements that occur repeatedly according to some placement rules. The other extreme is the stochastic (or random) texture, well exemplified by white noise. Most textures, however, occur somewhere between these two extremes [16, 12]. Indeed, loss of appearance is merely moving along this continuum. That is, strong textures move toward randomness.

The viability of our approach and others is firmly established in the literature for determining carpet appearance changes due to mechanical wear [8, 10, 11, 13, 14, 16–21]. In this paper, we extend our previous work to the study of changes in the appearance of hydroentangled and woven fabrics.

Experimental

MATERIALS

Our choice of fabrics is arbitrary. A woven fabric normally has well defined features and is expected to be quite durable. Nonwovens, on the other hand, are considered less durable. Our nonwovens consist of two very

[1] Current Address: Istanbul Teknik Universitesi, Makina Fakultesi, Tekstil Muhendisligi Bolumu, No: 87 80191, Gumussuyu, Istanbul, Turkey.

[2] Address for correspondence.

different textured structures. One is a loosely bonded hydroentangled nonwoven with a fairly well defined herringbone texture, and the other is a Miratec® fabric with a well defined twill texture. Our intent is not to undertake an exhaustive study of the differences between woven and nonwoven fabrics, but rather to demonstrate the viability of our texture analysis methodology in quantifying different textures.

To investigate the changes in appearance brought about by fabric-to-fabric abrasion, we used a crock meter as a wear tester. The fabrics were abraded at varying degrees and imaged on our image analysis system. The fabric characteristics and wear levels are given in Table I.

TABLE I. Fabrics and wear levels.

Fabric type	Wear degree, cycles
Woven twill fabric	control, 1000, 2000, 2500, 3000
Miratec® twill fabric	control, 1000, 2000, 3000
Hydroentangled herringbone fabric	control, 200, 500, 1000, 2000

METHODS

Image Processing System

Our capture device consisted of a high-resolution monochrome camera, a frame grabber, and a lighting system configured in our laboratory to provide a collimated dark-field illumination. The set-up is shown in Figure 1. The images were captured perpendicular to the focal plane of the camera. Our light source was a uniform LED light panel, and our images covered an area measuring 20 × 20 mm^2. Three images were captured for each sample, and the data reported are the mean and the standard deviation for the three replicates.

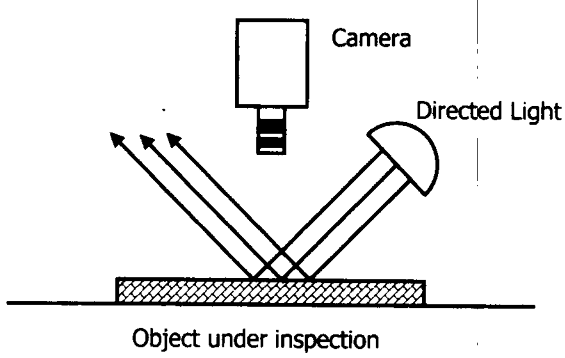

FIGURE 1. Illumination and capture set-up.

We preprocessed the images before co-occurrence analysis. We used histogram equalization with a standard algorithm [9], where gray level values are reassigned to produce a flattened histogram, making a more uniform gray level distribution and removing any biases caused by the variations in overall image intensity [6].

Spatial Co-occurrence

Texture units in a fabric consist of elements (*e.g.*, ridges in a twill fabric). However, wear (*e.g.*, abrasion) may modify these units through entanglement and loss of fibers. As a consequence, the periodicity (uniformity of texture) will be lost [11]. In this paper, we use spatial co-occurrence to evaluate periodicity in fabrics.

Co-occurrence analysis has been a powerful tool for texture analysis [3, 5, 6, 11, 13, 15]. Spatial co-occurrence examines the second-order, joint-conditional probability density function, $f(i, j|d, \theta)$, for the probability of sampling a pair of pixel positions with intensity values i and j, separated by distance d in direction θ.

The degree of spatial correlation is reflected in the co-occurrence matrix. If the intensities change over short distances, the frequencies will be spread more evenly across the matrix than if intensities change gradually over distance. A number of statistics have been devised to describe this spread, or moment, away from the main diagonal where $i = j$ (for a full description of this technique refer to Sobus *et al.* [13]). We concentrate here on *contrast* (otherwise known as *inertia*), defined as

$$\sum_{i=0}^{n} \sum_{j=0}^{n} \{(i-j)^2 M_{i,j}\} \quad .$$

Contrast is a moment statistic and is proportional to the degree of spread away from the main diagonal of **M**.

Spatial co-occurrence may also be used to investigate periodic patterns, since aspects of texture periodicity (amplitude, frequency, direction) will be reflected in the co-occurrence matrix [11]. For example, a repeating pattern with a period λ for which $\lambda > d$ implies that sampled pairs will have similar intensities, thus increasing the frequencies about the diagonal of **M**. If $d \approx \lambda$, sampling will generate a relatively uniform **M**. Each **M** is defined for a given set of d and θ, but one may compute a series of matrices for a range of d, say 1 to 100. Such a series would represent changing texture features over 100 pixels.

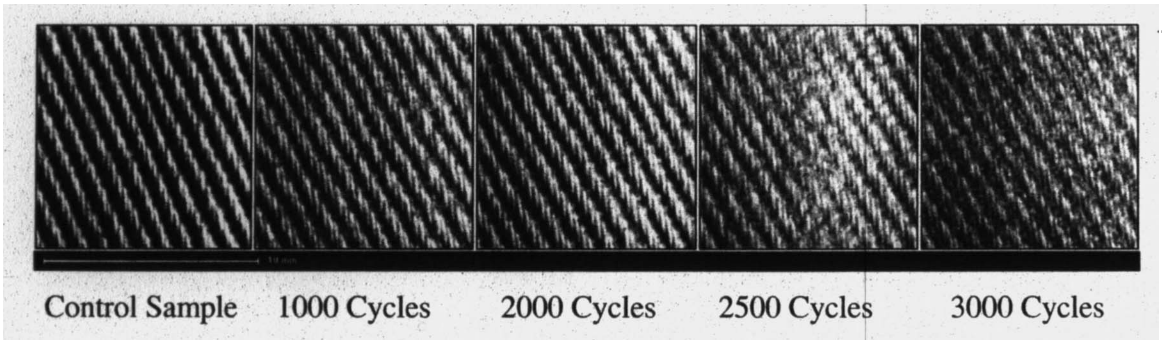

FIGURE 2. Images of woven twill fabric after abrasion.

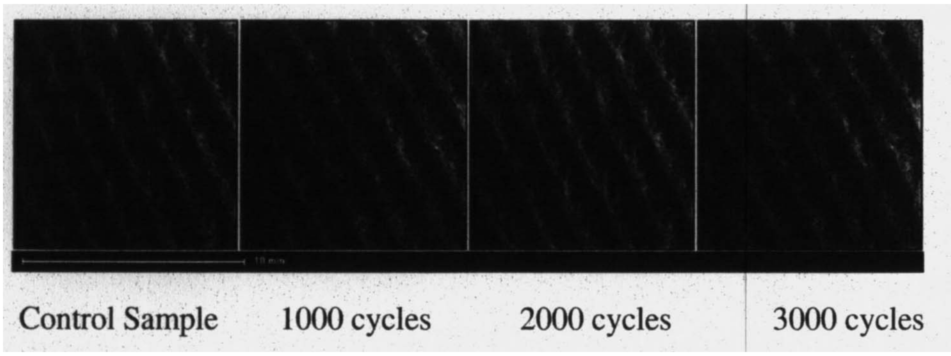

FIGURE 3. Images of Miratec twill fabric after abrasion.

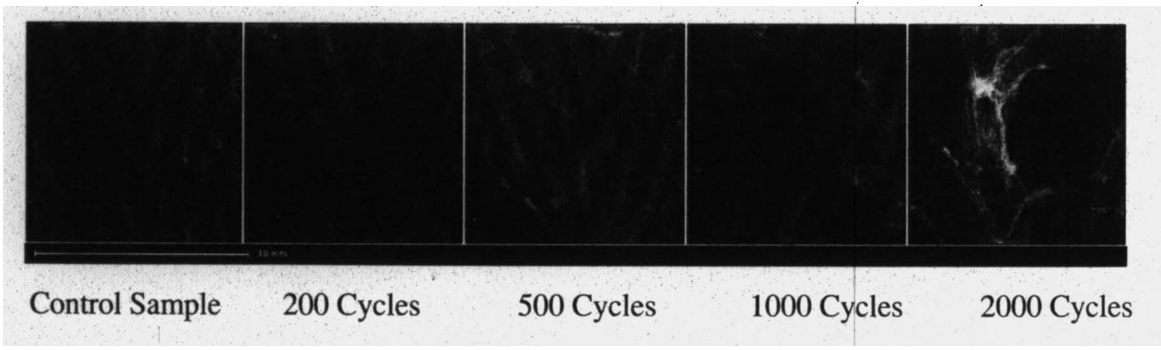

FIGURE 4. Images of hydroentangled herringbone fabric after abrasion.

We use the contrast statistic in order to measure texture differences. One may compute the contrast of matrices for a range of d, and contrast then becomes a function of distance. For an image generated by randomly sampling a uniform distribution, this function assumes a constant mean value. By contrast, an ordered texture produces a periodic function as the spatial correlation alternately falls and rises with distance. We have previously shown that the period of such a function is the period of the texture, and that the amplitude is an indication of the relative strength of the signal in terms of periodicity [11, 13].

We computed the contrast statistics for spatial co-occurrence matrices for the horizontal and vertical directions, for $d = 1$ to $d = 256$. We chose the latter value of d to facilitate spectral analysis of the contrast function. Sobus and Pourdeyhimi have shown that spectral densities can be used by employing a finite Fourier transform to compute the periodogram or power spectrum (the sums of squares of the sine and cosine coefficients for each of the Fourier harmonics), and that the magnitude of the periodogram indicates the statistical "strength" of the indicated frequency or the texture period [13, 14].

Results and Discussion

The images at various levels of wear are shown in Figures 2–4. Note that the woven fabric has been abraded, the texture definition is being lost, and the fabric surface appears to have become somewhat fuzzy. We can clearly see that fabric periodicity is shifted, and the magnitude of the contrast curves has become smaller as a result of abrasion, reducing texture definition. The Miratec fabric shows little evidence of wear. In fact, it appears that the marks present in the original control fabric have been covered and that the ridges in the final sample appear to be quite pronounced and intact. The loosely bonded herringbone sample, however, shows the greatest degree of wear. This is not unexpected because the fabric is lightly bonded to provide bulk and softness. Our visual observations are confirmed by examining the corresponding co-occurrence data for the samples given in Figures 5–7. For clarity, the co-occurrence data are shown only for the control and the highest level of abrasion; other intermediate levels of abrasion fall between these two extremes. Note that all samples have a periodic texture in both the horizontal (cross) and vertical (machine) directions. The vertical data for the herringbone fabric indicate two periods, due to the herringbone design. The woven fabric's co-occurrence data decrease in amplitude in both directions fairly significantly as a function of wear. The same is true for the herringbone fabric, where the texture is completely lost and the fabric begins to break up. The Miratec, however, shows little or no evidence of wear. In fact, the samples after 3000 cycles of abrasion appear to be somewhat better defined than the original control samples, partly because the abrasion has removed the texture variations between the ridges. This is demonstrated by Figure 8, where the intensity profiles are shown for the control and the worn samples. Note that the worn sample shows a smoother profile with a slightly higher degree of contrast. These can in turn result in higher co-occurrence measurements.

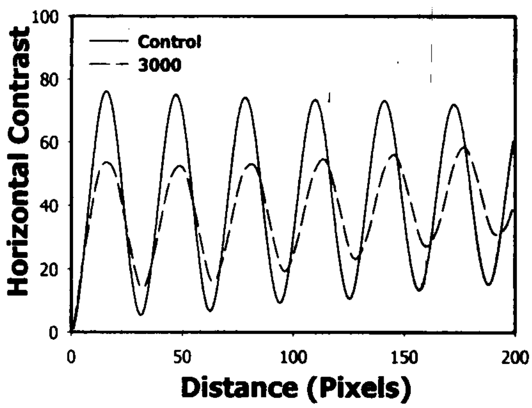

FIGURE 5. Co-occurrence results of woven twill fabric.

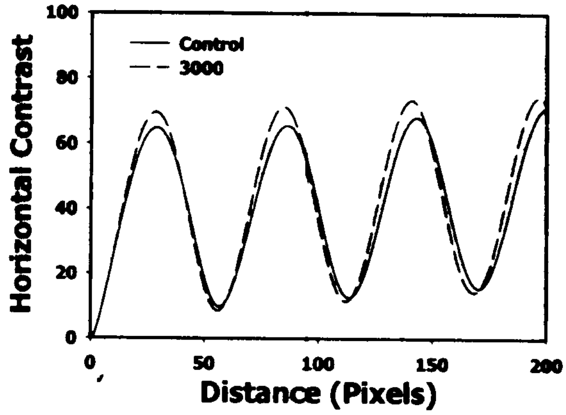

FIGURE 6. Co-occurrence results of Miratec twill fabric.

The data are further corroborated by the magnitude of the power spectra periodograms shown in Figures 9–11. The woven twill fabric shows a consistent reduction in periodogram power, the Miratec shows a slight increase, and the loose herringbone nonwoven shows a significant reduction with wear. The surface texture of the herringbone nonwoven is drastically changed by abrasion (see Figure 4). This fabric is the most flexible fabric among the fabrics we tested because it is loosely bonded (hydroentangled at low pressure). The appearance change was dramatic, even after 500 cycles, and it continued to change significantly at 1000 and 2000 cycles.

These results seem to indicate that co-occurrence statistics used as a function of sampling distance are sensitive to periodic changes of texture, and that spectral analysis is a good measure of the strength of the periodicity. Our investigation focused on the texture retention of each fabric independently, rather than comparing their physical structures.

Conclusions

This is a preliminary study of texture and texture retention in wovens and nonwovens. We conducted this study to assess the suitability of image analysis methods to determine texture and its loss. We have attempted to demonstrate the viability of co-occurrence analysis for texture retention after abrasion. We have confirmed that the co-occurrence methods are sensitive enough to structural and textural changes in the fabrics we examined.

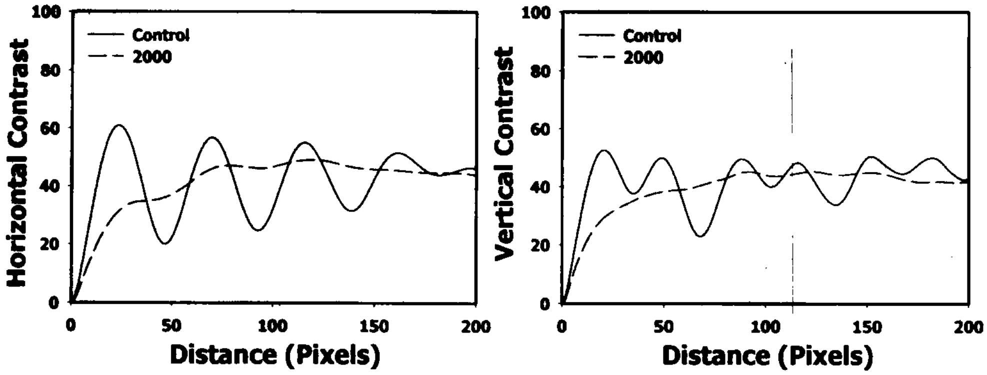

FIGURE 7. Co-occurrence results of hydroentangled herringbone fabric: horizontal (left) and vertical (right).

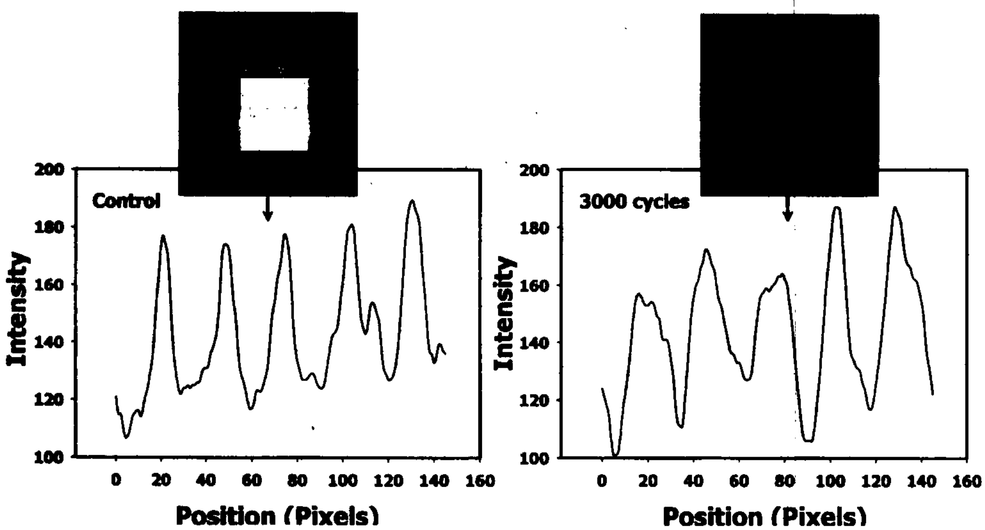

FIGURE 8. Intensity profiles for Miratec twill fabric.

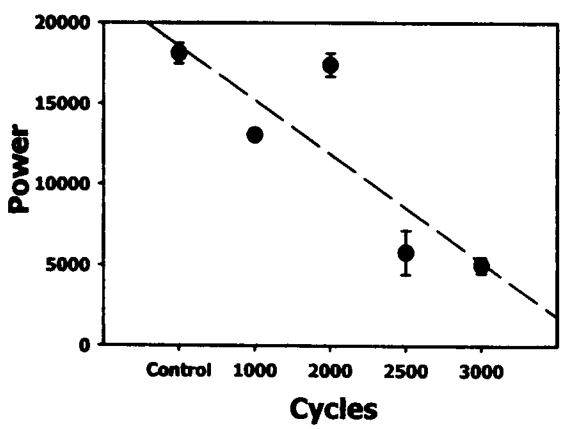

FIGURE 9. Frequency analysis of contrast data for woven twill.

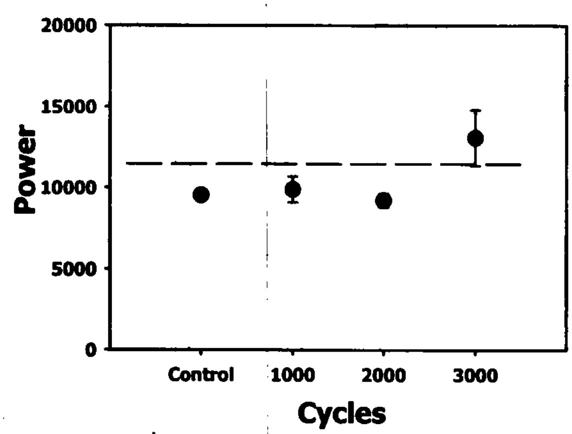

FIGURE 10. Frequency analysis of contrast data for Miratec twill.

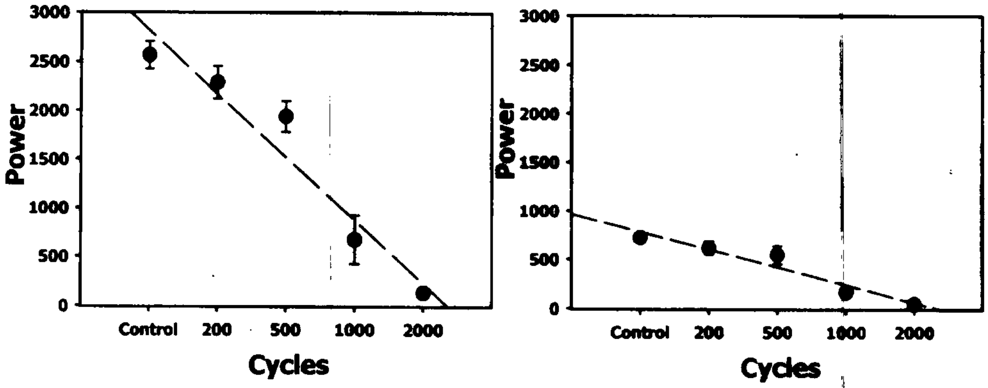

FIGURE 11. Frequency analysis of contrast data for hydroentangled herringbone fabric: horizontal (left) and vertical (right).

We have also previously found these methods to be reliable in determining appearance retention in carpets [11, 13], and we offer them as a means to objectively evaluate the textural properties of fabrics and the loss thereof.

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