# Measuring hairiness in carpets by using surface metrology

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## ABSTRACT

Recently, an automatic system for grading appearance retention in carpets using our own scanner and image analysis techniques was proposed. A system for carpets with low pile construction and without color patterns has been developed. Appearance changes in carpets with high pile construction were still not well detected. We present an approach based on surface metrology that extract information given by the hairs on the carpet surface. These features are complementary to the texture features previously explored. By combining both features, we expand the use of the automatic grading system including some carpets types with high pile construction.

**Keywords:** Carpet Wear Assessment, Hairiness Analysis, Image Analysis

## 1. INTRODUCTION

Carpet manufacturers assess the quality of carpets by evaluating the appearance retention (AR) grade. These assessments are based on the standards ISO 9405 and EN1471.[1,2] For this evaluation, new samples are undergo to a mechanical system which simulates the traffic exposure.[3,4] Then, the quantification is done by experts, who by means of visual inspection, evaluate appearance lost and structural degradation.[5] The evaluation is done by comparing the original (new) zone with the fatigued zone of the carpet. Finally, the appearance retention grade is defined by numbers between 1 and 5 in steps of 0.5, where carpets with original appearance are graded 5 and carpets with severe overall changes are graded with 1.[2,5]

Thus, the evaluation is given under a subjective evaluation of the change in surface appearance. The changes between unexposed and exposed regions are evaluated under the assessment of different physical features. Some of the most relevant features to be visually evaluated are: textural change, hairiness, change in color among others. The selection of the relevant features to describe the appearance changes for a particular kind of carpet is done according its nature. Currently, each characteristic is separately evaluated by human experts. Carpet manufacturers are highly interested in reducing the subjectivity in the current quality assessment method performed.

Several approaches using image processing have been performed in search of an objective carpet wear assessment.[6–10] Most of them are focused in texture analysis.[9,11,12] Also, approaches related to assessment by using changes in intensity color have been developed.[13] All these researches have shown promising results, mainly to assess carpets type cut and loop pile.

For carpets with high pile construction (shaggy carpets), an automatic assessment has not been fully successful given that, for some of them, the texture and the color do not change strongly. Therefore, texture and color analysis have not been enough for evaluating shaggy carpets properly. Then, additional features must be inserted to contribute for a suitable automatic assessment in shaggy carpets. This need was also found in measuring the quality of textile surface.[14] In that approach, Xin described the needs for additional characteristics

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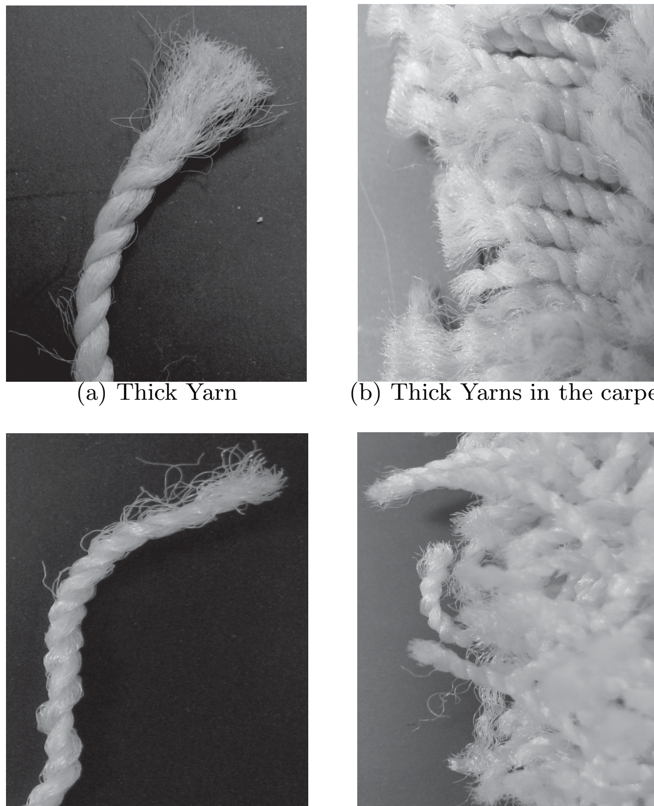
to evaluate the quality of fabric appearance.
In carpet wear assessment, we have previously developed a scanner specifically designed for this purpose.[11] This scanner has permitted to capture the structure of the carpet in a depth (range) image. Approaches based on texture analysis for carpet wear assessment have been developed by mean of our scanner.[10,12] Shaggy carpets with thin yarns have been the strong challenge for the assessment, principally for the the aforementioned problems. Thus, additional features must be extracted to assess properly the AR grades in shaggy carpets.
Particularly for shaggy carpets, the characteristic of hairiness is strongly connected to their appearance changes. In the case of carpets subject to the traffic simulators, the hairiness is mainly perceived in the head of the yarns. This hairiness is given by an untwisting of the yarns which open the fibres in the top of the yarn. Thus, for shaggy carpets, the quantification of the changes in hairiness between original zone and worn zone can strongly contribute to an objective assessment.
Several research in hairiness have been performed for analyzing the quality of the fiber.[15–20] The hairiness analysis is usually applied in the production process of the fibers. In most of the researches, hairiness analysis is done for a separated fiber observed by microscope. Actually, automatic systems for hairiness analysis are using for analyzing the quality of the fiber in textiles during the production process.[20] In those systems, the hairiness is quantified by measuring the number of hairs, the length of the hairs and the density of the yarn.[15,19] For the carpet wear assessment, according to the standards, the carpet must be analyzed in the entire carpet and the carpet can not be touched by the expert. Thus, to remove yarns of the carpets for the hairiness analysis is not possible.
On this paper, an algorithm to extract the grade of hairiness by mean of the extracted images by our scanner is proposed. This algorithm permit quantify the hairiness changes visible on the surface of the carpet captured by a reconstruction based on a laser strip line. The quantification is based on surface metrology using as references the different approaches of hairiness analysis. The collected information is compared with the appearance retention grades of the carpets to establish the connection between the AR grades and the information obtained. We use this new measurement as complementary information for an automatic assessment in shaggy carpets.
This paper is organized as follows: We first describe in Section 2 the carpets to be evaluated by our proposed method. Secondly, in Section 3 the approach is described. Then, in Section 4 the experiment conducted to evaluate the performance of the approach is explained. Afterwards, results are reported in Section 5. Finally, conclusions are drawn in Section 6.

## 2. MATERIALS

For this research we used two different sets of shaggy carpets established by the $EN1471$ European standard.[2] Each reference contains eight carpet samples corresponding to each AR grades. Two samples of the references used are shown in Figure 1. One reference of shaggy are carpets with thin piles (frise) (Figure 1(a) and 1(b)) and the other carpets with thick piles (Figure 1(c) and 1(d)). In each reference, eight degrees of surface degradation are defined. The degrees are specified by using AR grades. The AR grades vary from 1 to 5 with steps of half point, where a AR grade of 1 represents a severe change of a fatigued specimen whereas an AR grade 5 represents an original sample not exposed to any traffic exposure mechanisms. After the traffic simulation, samples have a exposed (worn) region in the middle of the carpet and a unexposed (new) region on the sides. The references has been previously digitalized by our scanner, which was specifically developed for carpet wear assessment. This scanner was designed to capture the surface profile of a carpet placed on a drum.[11] The surface profile was reconstructed in a range image by using by a wavelet edge detector.[21] Thus, a database of surface profile images of a set of carpets with different references and their different AR grades was composed. Additionally, the database contains the frames of the raw video obtained by scanning the lighted cross sections of the carpet. The frames are images $720 \times 640$ pixels in gray scale of the lighted region by the laser strip line. Thus, for this work we use the images of the frames from our scanner for each carpet of the selected references. These images contain as the profile surface as the hairiness of the carpet. In the image, the surface profile is the predominant lighted line by the laser while the hairiness usually related to the isolated points placed on the surface profile. Each pixel in an image represents the depth of the surface in an area of 0.24 $mm$ by 0.24 $mm$.



(a) Thick Yarn (b) Thick Yarns in the carpet

(c) Thin Yarn (d) Thin Yarns in the carpet

Figure 1. Samples of the carpets

Figure Samples of the Carpets shows the yarns of two types of references used in this work. Figures 1(a) and 1(b) correspond to one sample of a shaggy carpet with thick yarns. Figures 1(c) and 1(d) correspond to one sample of a shaggy carpet with thin yarns.

## 3. METHODS

In this work, an algorithm to extract the grade of hairiness by using images from our scanner is proposed. This algorithm permit quantify the hairiness changes visible in the surface of the carpet based on images of the reflections of a laser strip line. The quantification is based on surface metrology using as references, different approaches of hairiness analysis. The collected information is compared with the appearance retention grades of the carpets to establish the connection between the AR grades and the information obtained. We pretend to use this new measurement as complementary information for an automatic assessment in shaggy carpets.
The proposed measurements are based in methods originally developed for hairiness analysis of a separated yarn. These methods measure the hairiness in terms of the number of protruding fibers and their lengths. In our approach, the measurements are performed evaluating the changes in the hairiness principally observed in the top of the yarns. Following the methods are explained. Then, the proposed adaptations of the methods for measuring hairiness in carpets by using our scanner is explained.

### 3.1 Hairiness measurement

Several research in hairiness have been performed for analyzing the quality of the yarn.[15, 17–20] The measurement of hairiness is developed by diverse methods based on different physical principles.[22] In,[15] a compilation of several techniques and also various instruments designed for measuring hairiness is shown.
For hairiness, there is not an standard definition and its measurement is method dependent.[19] In most of the researches, the evaluation is principally done by taking a separated fiber observed by microscope.[16] In other

cases, automatic systems for hairiness analysis have been developed for on-line monitoring and control of the yarn production processes. In those systems, the yarns hairiness is usually quantified by measuring the length of the hairs and the number of hairs per unit length.[19]

#### 3.1.1 Yarn cross-section analysis

Looking the fiber in a cross section, the yarn compact body can be represented as a circle with radio $r_D$. Fibers protruding from the yarn body resulted of the hairiness. The hairiness can be delimited in an external circle with radio $r$. Thus, the packing density of the hairiness is given by

$$\mu = (\mu_D r_D / r) 2^{-(r - r_D)/h}, \quad (1)$$

where $\mu_D$ is the initial packing density corresponding to yarn radius $r_D$ and $h$ is the half-decrease interval of the number of protruding fibers.[18]
Thus, this approach quantify the hairiness as the density $\mu$.

#### 3.1.2 Length and area of the yarn analysis

The intrinsic hairiness can be measured only by measuring the true length of all the hairs and dividing it by the length of yarn.[17] In some cases, there are a large number of hairs very close to each other which makes impossible to measure the hairs separately. In that case, The area covered by hairs was found to be such a measure. Thus, the total covered by hairs is divided by the area of the yarn core to obtain a dimensionless quantity which was called hair area index.[17, 19]

$$Hairiness_{index} = area_{total} / area_{yarn}$$

The commonly used instruments today work on two different principles. One of these is to shine light on the yarn and detect the diffused light scattered by the hairs. More hairs and longer hairs scatter more light. The other type of hairiness tester scans the yarn with narrow bands of light at different distances from the body of the yarn. A more hairy yarn causes less light to pass through.[17]

### 3.2 Proposed adaptations

For carpet wear assessment, according to the standards, the carpet must be analyzed in the entire carpet and the carpet can not be touched by the expert. Therefore, to remove the yarns of the carpets for the hairiness analysis is not possible. Thus, the measure must be done in all the carpet as an average quantification of the hairiness for all its yarns.
For this purpose, a new information extracted from our scanner is proposed. This information is collected from each image captured by the scanner. The images taken in reflected light contained regions where light was reflected from the fibres.[17] Thus, each image contains the cross-section information of the carpet captured by mean of the structured light. Besides, each image contain particular information related to the surface profile and hairiness of the carpet. Thus, the surface correspond to the connected information in all the strip line while the hairiness are related to groups of isolated pixels on the surface profile.
We define a base line as the upper border of the surface profile. The surface profile was built by defining pixel clusters of lighted regions by the structured light the after an automatic thresholds of the image. Thus, the surface profile is contained in the bigger cluster of each points of $x - coordinates$ in the image. The points in x-coordinate which do not contain clusters are interpolated to establish the base line. Thus, the hairiness is mainly over the base line obtained. This hairiness is related to the fibers protruding of the heads of yarns which are placed over the surface profile.
Thus, with the clusters of the surface profile and the clusters of the hairiness two measurements were proposed: The density of the light through the clusters and the length of all the clusters identified as hairs.

1. **Length of the hairs**, Given the cross section of the carpet lighted by the laser, the lighted isolated points correspond to the cross section of hairs over the surface. The result of summing all these points will be the total length of all hairs in the carpet.

2. **Density of the yarn** The lighted cross section of the carpet is composed by hairs and yarns captured by the laser. Making clusters around the yarns is possible to quantify the density of the yarn based on the intensity changes. Based on that, the intensity changes will reflect the relation between the body yarn and the hairiness according the yarn cross section analysis.[18]

## 4. EXPERIMENTS

To evaluate the hairiness, we use two available sets of shaggy carpets: tick yarns(Carpet 1) and thin yarns (Carpet 2) with their AR based on the Europe carpet-appearance standard EN1471. The information of the cross section for each sample is extracted from the frames explained in section 2. The information is obtained based on the proposed adaptation in section 3. The indicators are computed comparing the worn regions of the samples against the region with original appearance. Finally, we evaluated the indicators for distinguishing the related AR grades.

The evaluation is based on an analysis of variance (ANOVA). The performance is evaluated based on the principle of monotonicity and variability. These measures are described as follows:

1. **The monotonicity (M)** evaluate the order-preserving between the extracted features and the related AR grades. This is computed by Spearman rank correlation, termed $\rho$.[23] To compute the Spearman rank correlation, the texture features must be first ordered from small to large and then computed under the eq. (2).

$$\rho = 1 - \frac{K}{(G)((G)^2 - 1)} \sum_{g=1}^{G} {d_g}^2 \tag{2}$$

   Where, $d_b$ the differences between an assigned rank and an expected rank. $g$ is the index of the $G$ number of differences $g = 1, \ldots, G$. $K = 6$, a constant defined by Spearman.

2. **The variability (V)**, defines how well the total variation in the AR grades can be explained by the linear relation between the obtained values and the AR grades. The adjusted coefficient of determination, termed, $R_a^2$, is used[23] to quantify the variability. $R_a^2$ is defined as:

$$R_a^2 = 1 - \frac{n-1}{n-p-1} \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \bar{y})^2} \tag{3}$$

   Where $y_i$ is an AR grade computed from the features, $\hat{y}_i$ is the estimated AR grade assessed by humans and $\bar{y}$ is the mean of the $y_i$ values. $p$ is the total number of parameters in the linear model $\bar{y} = \alpha + \beta\bar{\mu}$, $n$ is the number of values per sample size.

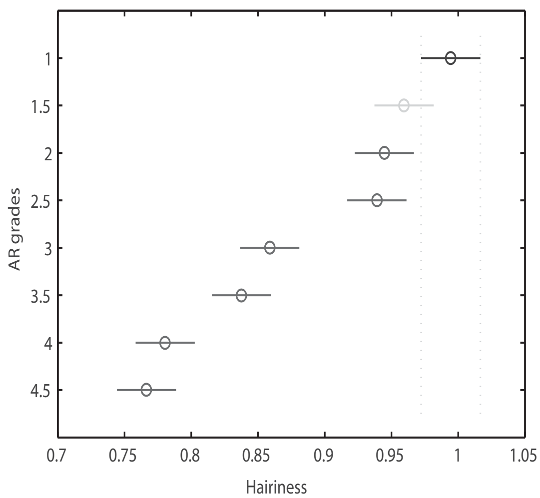
## 5. RESULTS

We have compared the performance of the two proposed approaches in discriminating AR grades using samples from two set of shaggy carpets from the European standard. We found a relation between the extracted feature based on hairiness and the the AR grades. This evaluation was performed based on monotonicity and variability in the description of AR grades. The results are listed in Table 1. Table 1 shows the measurements of monotonicity and variability obtained by evaluating *lenght* and *density* approaches:

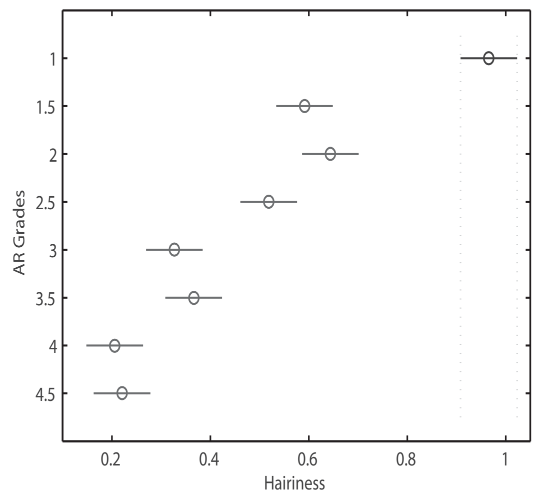
The results show that the monotonicity is better in the density approach compared with the length approach, achieving a good description of AR grades with the hairiness values ($M = 0.94$) in shaggy with tick yarns (Carpet 1). Nevertheless, the performance for both approaches for the shaggy carpets of thin yarns (Carpet2) is not completely monotonic ($M = 0.75$).

| | Density | | Lenght | |
|---|---|---|---|---|
| | $M$ | $V$ | $M$ | $V$ |
| Carpet 1 | 0.94 | 0.92 | 0.91 | 0.84 |
| Carpet 2 | 0.75 | 0.68 | 0.64 | 0.53 |

Table 1. Monotonicity(M) and Variability(V) to distinguish AR grades in carpets by two hairiness approaches based on length and density




(a) Hairiness based on density




(b) Based on length

Figure 2. Hairiness approaches

Figure Hairiness approaches shows the performance of the two approaches to distinguish AR grades in a set of shaggy carpets with thick yarns. Figure 2(a) corresponds to the density approach against AR grades. Figures 2(b) corresponds to the length approach against AR grades.

Figure 2 illustrate the relationship between AR grades and the proposed hairiness measures on a set of shaggy carpets. In Figure 2, the hairiness corresponding to AR grades are displayed with box coxes, where the center of a cox box is the mean value and two lines at the right and left of each cox-box represent its standard deviation. In Figure 2, the density approach (Figure 2(a)) show a better distribution of the box cox compared with the length approach (Figure 2(b))for distinguishing AR grades.

## 6. CONCLUSIONS

Two approaches to measure hairiness for distinguish AR grades in carpets was presented. The approaches are based on length and area measurements. The techniques have been tested on two set of shaggy carpets. The results show that both approaches shows the relationship between AR grades and hairiness in shaggy carpets. Particularly, the approach based on density performs better than the length approach for distinguishing consecutive AR grades. Given that both approach do not permit distinguish consecutive AR grades, the information of the hairiness must be used as complementary information of other features as texture or roughness for distinguishing of the different AR grades.

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