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Assessment of a Fabric Surface after the Pilling Process Based on Image Analysis

Abstract
This study presents the principles of a new method of assessing a pilled fabric surface, especially knitted fabric surfaces. The basis of the method developed consists in analysing a knitted fabric surface after the pilling process by using colour digital images (RGB model). Application of the RGB model for the images acquired allows to differentiate pilling and fuzzing changes more effectively and precisely. Analytical techniques make it possible to conduct a digital analysis of images of pilled fabrics and then to obtain a certain grade of the pilling value conforming to the standards. At this stage of the research, the analytical methods used to assess the pilling process are being improved to obtain more precise effects.

Key words: *computer image analysis, pilling, pilling grade, assessment of changes in the pilled surface, objective pilling assessment.*

Introduction

Pilling is an important problem not only for textile and clothes manufacturers but also for users. The effect of the pilling process results in a significant decrease in fabric quality and a negative influence on the user's comfort. At present attempts to classify and standardise textile quality requirements for textiles devoted to clothing manufacturing pilling tendency plays a very important factor. The acceptable value of the pilling rating for woven fabrics is 3 (according to PN EN ISO 12945-2:2002; after 2000 rubs, and for knitted fabric it is also 3, but the test is carried out according to PN EN ISO 12945-1:2002; after 7200/14400 revolutions). These levels of pilling grade force producers to pay special attention to decreasing the pilling tendency [1]. Moreover, pilling is a very important factor in analysing new spinning techniques, so that textiles (knitted and woven fabrics) produced from such new yarn show a lower and lower pilling tendency [2 - 4].

Stages of pilling evaluation

According to the terminology presented in PN-EN ISO 12945-2:2002, pills are fibres entangled of into balls, which stand proud of the fabric and are attached to it. The structure of a pill is characterised by such a big density and fibre entanglement that a ray of light is not able to pass through it, thus casting a shadow. The pilling process is a result of interaction between friction forces in contact with the fabric surface during wearing, cleaning or washing.

Fuzzing is defined as a roughening of the surface fibres and/or the teasing out of fibres from the fabric, which leads to a visible surface change [5].

Both types of changes described could occur during washing, dry cleaning or wearing.

The pilling process [6, 7] can be generally described as both the development and disappearance of pills which occur in the following four stages:

1. Development of down on the surface of fabric resulting from the migration and progressive extraction of superficial fibres out of the yarn – the process of fibre combing

2. Development of a pill through the entanglement, interlacing and winding of the fibre extremities coming out of a yarn. A part of the fibres is broken due to multiple flexing and stretching, and in consequence it forms rolled aggregates. These aggregates occur as a result of mutual movements transforming into so called, 'kernel pills'. Impurities can also be active in developing a pill's core. This situation is especially visible in the case of pilling on fabrics made from yarns and fibres with an extremely developed surface structure. Hydrophobic fibres are more susceptible to the attack of impurities than hydrophilic ones due to their electrostatic properties.

3. Progressive evolution of the size of a pill core occurs until a certain stabilisation is observed. It is when the fabric surface is in this state, when the size of existing pills does not increase, that new pills do not appear. This state is sometimes difficult to identify because all pilling stages are closely linked, and fabrics show differentiated behaviour depending on the composition, stitch, kind of yarn and finishing type.

4. The disappearance of pills may be due to the clustering of friction forces exerted on the pill's core, which generate axial tensions in the fibres. This process, called 'self cleaning'', appears in the case of synthetic fibres or some natural fibres (for example wool fibre), which are characterised by a weak breaking load and weak flexural strength.

The pilling tendency of fabrics depends on a lot of different factors. Various factors can have an effect on the pilling structure (the number and size of pills appearing on a fabric surface unit). As our research works were carried out only on knitted fabrics, all conclusions will refer to these fabrics But the new method of assessment can be applied to woven fabrics as well. However, further investigations would be advisable.

The following is a list of factors which can have an effect on the pilling tendency of knitted fabric:

- fibres (tenacity, length, level of crimping, fineness);
- yarn (linear density, value and direction of twist, hairiness, friction coefficient, composition, spinning process);
- adjustment of spinning machines;
- knitted fabric (stitch construction, number of courses and wales per unit length, length of yarn worked-in);
- finishing (e.g. mechanical action during aqueous treatments, streaming temperature, dyes used, etc.).

Pilling assessment methods - literature survey

Nowadays, there are a few standardised methods of pilling tendency assessment, for example ASTM, AATCC, IWS, BIS, JIS and two ISO standards: ISO 12945-1:2000 and ISO 12945-2:2000. These methods determinate the category of machines to be used to simulate wearing e.g., the Martindale abrasion tester or pilling the box. However, the criteria and usage of visual assessment are common in both of the ISO standards. The standards define 5 grades of pilling intensity (shown in ***Table 1***), conditions of illumination and sample positioning during assessment [8].

This method is labour consuming as it requires more than one observer to assess the specimens. (now, at least two persons can perform it – according to ISO 12945-2:2000). This method is also very subjective as the different experience and individual visual perception of observers are considered. Hence, for many years there have been attempts to form an objective and automatic assessment of pilled fabric surfaces.

The first attempts were based on the simple counting of the number of pills on a fabric surface. These pills were then removed from the fabric surface by a sharp razor blade and weighted in a torsion balance [9, 10]. Richards [10] and Williams [9] found that this method gives a clear picture of the pilling tendency of a fabric in real wearing conditions. The pilling intensity is defined by the mean pill mass and mean pill number. This method is extremely laborious, time-consuming and requires a specimen of substantially greater size. The next researcher to study pilling – Konda [11] - used an image analysis system with a video camera to evaluate the pilling grade. An image of the sample is captured with a video camera of 240 × 256 resolution. The image is then transformed into a grey scale and converted into a binary system. Similarly, images of the standard photograph are captured and converted into a binary form. Later both images are compared, and then a suitable grade of pilling is assigned.

Recently, research works have been published on this subject [1, 12], based on computer analysis tools. The majority of the work was carried out by Behera and Mohan [12]. The system designed by them consists of a closed chamber with a controlled illumination system of cameras registering a sample image and a computer enabling further image processing. The Fourier transformation is used as a basic technique of computer image analysis (FFT-Fast Fourier Transform, DTF-Discrete Fourier Transform) [13]. This method uses the phenomenon that both not uniform and irregular objects on the fabric's surface have their representations in the analysis of the power spectrum – a result of DFT. Elements of a sample structure regularly repeated (stitch or pattern) are represented in the spectrum by different frequency values. Thus, if we eliminate some of the spectrum range (the spectrum's peaks or values below the quantity assigned) and a carry out reverse transformation, we can obtain an image of interesting parts in a binary form [1, 12, 13].

Table 1. *Visual assessment of pilling according to ISO 12945-2:2000 [4].*

Grade	Description
5	No change
4	Slight surface fuzzing and/or partially formed pills
3	Moderate surface fuzzing and/or moderate pilling. Pills of varying size and density partially covering the specimen surface.
2	Distinct surface fuzzing and/or pilling. Pills of varying size and density covering a large proportion of the specimen.
1	Dense surface fuzzing and/or severe pilling. Pills of varying size and density covering the whole of the specimen surface.

The disadvantage of this method is the sensitivity of the fabric surface to disturbances, which are not pills, but their equivalents in the spectrum frequency are placed in the same range as pill equivalents.

This method is not suitable to extract from the spectrum image those frequencies which are responsible for fuzzing, because the fuzzing effect does not appear as strongly as the pilling effect at the brightness level.

The technique of extracting pills from a woven fabric surface, presented by Behera and Mohan [12], does not allow to recognise changes in fabric surfaces of lower intensity (such as groups of entangled fibres, fuzzing etc). Moreover, when analysing samples of high pilling concentration and regular pilling distribution, the interpretation of the image spectrum could be incorrect. It can cause a rejection of those parts of the spectrum which are responsible for pilled surface changes. The organoleptic assessment commonly used nowadays is highly subjective and laborious. Other alternative methods (using image analysis) developed by Konda, Behera and Mohan [10, 11] are presently research works and as yet not applied in practice.

The main subject of this work was the development and further the improvement of a new method of objectively assessing the pilling of a fabric surface, especially on knitted fabrics. This new method was based on computer image analysis using raster graphics tools.

Contrary to the above mentioned methods, the new method presented here is not founded on frequency spectrum analysis. It was possible to carry out surface image analysis of greyscale or colourimages. This latter kind of image gives better information about pilling intensity than the monochromaric mode.

The new pilling assessment method

The new assessment method presented herein, uses colour images consisting of the three (RGB) model channels.The name of the RGB model comes from the initials of the three additive primary colours: red, green and blue. This method allows to reduce laborious pilling assessment. Using analyses and the processing of colour images (saved in the RGB model), the new method allows for a more precise separation and calculation of changes in a pilled surface and the area affected by this process. In the research works published thus far, there has not been any attempt to assess pilling by means of colour image analysis, in order to separate pilling changes from a fabric structure.

The new method presented in this paper is based on a few, commonly used, computer image analysis tools. In this method the data which make it possible to characterise changes in the surface structure of a fabric after the pilling process are extracted from the digital images acquired. It also makes it possible to take into consideration the consecutive, coexisting stages of the pilling process.

The main idea of the method presented is an analytical approach to the RGB images obtained [14 - 16]. The color is expressed as an RGB triplet, each component of which can vary from zero to a defined maximum value.

It is defined as:

$$f(x,y) = f_R(x,y) + f_G(x,y) + f_B(x,y) \quad (1)$$

where:
$f_R(x,y)$, $f_G(x,y)$, $f_B(x,y)$, - brightness level for RGB components

The advantages of using the RGB mode in present-day image analysis are the simplicity of technical realisation and the low cost of calculation (the possibility of large calculations due to processors and graphic processors currently used). There is times a need to present an image as three various images, each in one of the colour components only. This is a colour separation process, which allows to separate each image channel and then to study the dates obtained by using selected algorithms [14].

The scheme presented in Figure 1 illustrates the basic stages of the new pilling assessment method. The main purpose of this procedure is to choose the best parameters for the machine vision scene [15], which are components of the acquisition's entire environment. These components of the acquisition's environment are the most numerous of all the object features (in the analysis described, this element is difficult to identify because of its irregularity): illumination, kind of background, and optical configuration. An image of the sample is captured in the RGB mode. Later, each channel is analysed - the red, green and blue are presented in the form of independent images in a brightness scale from 0 to 255, which is used to distinguish object features that are important to us: parts of the surface where there are changes due to the coexisting stages of the pilling process. Then the image is laid on several channels in sequence (the selection of channels and their sequence depend on the illumination conditions during acquisition as well as sample features: colour, surface structure, and pilling intensity). Then the blending mode is chosen which is the best for a given sample. Each of the blending modes used calculates the values of the brightness level for particular pixels in a newly created channel. The most frequently used blending modes in this method are multiply, screen, difference and options from the Light group (Hard Light, Vivid Light, and Overlay). At this stage of the research work, the choice of blending mode depends on the operator. This is a subjective component of this new method, which will be subject to its automation. However, in future works the most effective blending modes will be used for all fabric colours and structures tested in order to automate the assessment method.

In the process of pilling separation, this solution will cause minimal or no influence for the observer. For example, the blending mode – multiply causes the whole image to darken, but passages between brightness levels are smooth. The blending stage in this method is necessary to separate the pilling and fuzzing of the structure of the fabric surface. The blending modes described in this paper are available using one of the raster graphics programs. The next stage in this method is the thresholding of the image prepared in order to cut off these levels, which are responsible for pilling and fuzzing changes on the surface. The image obtained in this way is ready to be used in the calculation of the pilling and fuzzing area and next to relate this to the area of the total image. However, in future works it is necessary to compile algorithms ensuring more precise blending input image channels irrespective of the diversity of prime features of the image (colour, way of illumination, time of exposition).

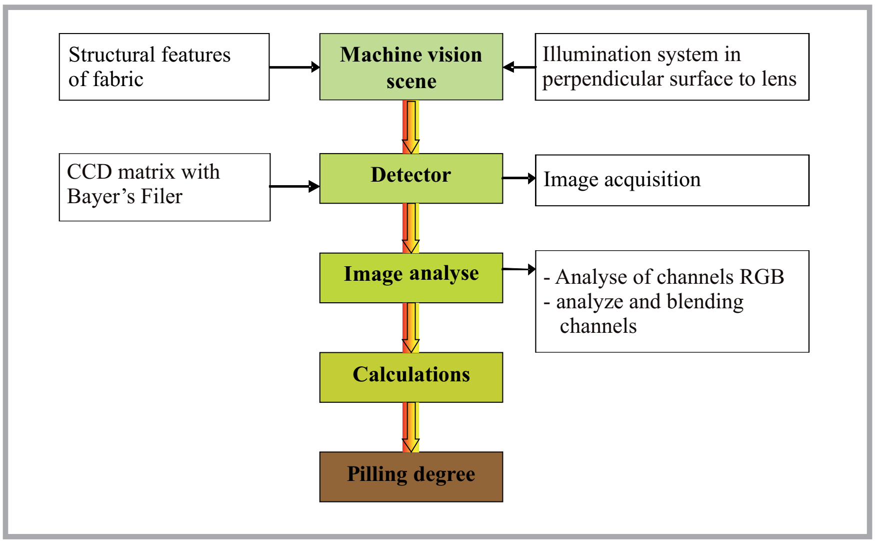

Figure 1. *Stages of the new pilling assessment method.*

Experimental

Analytic surveys were carried out in which plain jersey knitted fabrics made of cotton and polyurethane yarn were the test objects. Samples of these fabrics were pilled according to Standard ISO 12945-2:2000.

A machine vision scene with detector was acquired by an image grabbing system. At this stage of work the system consisted of a biological microscope with a 1x zoom lens, a set of optical fibres for sample illumination at a chosen angle and a digital camera used to capture an image from the microscope. Moreover, the microscope was equipped with a motorized Z stage (an accessory for automatically capturing all-in-focus images). The image was captured with different focuses and could be combined to create a multi-focus image. It was the end of image capturing stage. The image was then ready for further analytic processing. In future stages of these research works, this system will be rebuild to capture the whole sample area.

Figure 2 presents a digital RGB image of pilled surface parts obtained using the image grabbing system described above.

Figure 2. *Image of pilled surface.*

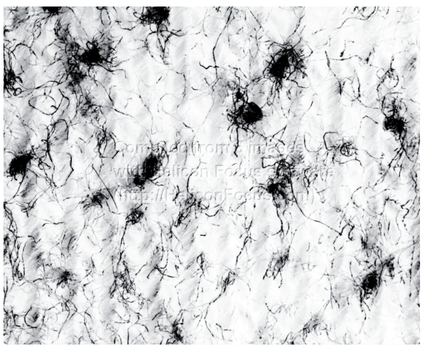

Figure 3. *Image of test sample with an extracted pilled surface.*

In the next stage of the tests, the operator analysed each of the image channels and used the blending mode – multiply (for the channel's Green and Red inverse, the Green channel was a source). The choice of blending mode was made by the operator. Extraction of appropriately analysed image components was the result of this operation, which is shown in ***Figure 3***.

Subsequently, only interesting values of the brightness levels in the image were left. At the same time all – objects of interest (in contrast with the background colour) were marked i.e. the areas which would be calculated in the next stage. The calculation of marked areas was carried out using an NIS Ar program. All of the pilled surfaces extracted were appropriate and selected and calculated effectively.

Next, values of the total area of the image and those of the pilled surface were calculated.

As a result of the analysis performed, the percent rate of the pilled surface (considering all pilling stages) was calculated and compared to the total area of the image.

The percent of a pilled fabric surface is given by:

$$N = N_p / N_c \times 100\% \qquad (2)$$

where:
N - pilled fabric surface, %
N_p - area of pilled surface, pix^2
N_c - total area of captured image, pix^2.

The area of pilled surface is given by:

$$N_p = \sum_{i=1}^{n} N_I + \sum_{j=1}^{m} N_I + \sum_{k=1}^{l} N_{III} \qquad (3)$$

where:
N_I – area of pilled surface - first stage of pilling, pix^2
N_{II} – area of pilled surface - second stage of pilling, pix^2
N_{III} – area of pilled surface – third stage of pilling, pix^2

The *Np* components were not determined individually: they were used only for information that in the calculation were included all pilling stages. The *Np* values were determined according to tests, as given in ISO 12945-2:2000, on selected groups of knitted fabrics.

The *N* value calculated according to equation no.1 we can relate to the pilling intensity assessment actually used (according to ISO 12945-2:2000 [5]). Comparison of the *N* value (as symbols) and pilling grade is shown in ***Table 2***.

The values x_1 to x_6 could be assigned after a long series of tests carried out on groups of similar fabric samples. In this way we obtain an x_i value correct only for this fabric group or type. Xi values could be similar, but not the same, for different kinds of fabrics (type of fabric, stitch construction, composition etc). Furthermore, it is necessary to carry out an initial test (capture image and analyse it) of the non-pilled fabric surface to define the surface fabric appearance before the pilling process. This task allows to compare the fabric surface during tests before and after the pilling process.

Conclusions and summary

The development of a new, objective method of pilling tendency assessment is very important to make it more uniform and more objective than the standard method presently used. The most subjective factors in the standard method are the visual perception and experience of observers. The new method allows to increase assessment precision and the repeatability of the pilling assessment. The main advantage of the new method is replacing the organoleptic technique of pilled surface assessment by a new technique which uses computer image analysis and the raster graphics method to detect and calculate pilled changes on a fabric surface. The new method is more objective than the organoleptic analysis used nowadays, but there are still subjective components (certain operations of raster graphics analysis). Moreover, the method developed allows for not only a more complete (by using IT techniques) analysis of a pilled fabric structure but also recording images, analysis results (for comparison analysis), which are not possible in the method currently used. The next stage of the research works will be the elaboration, presented in this paper, of the classification of the pilling grade using the N value for different groups of fabrics. It would allow to develop a database of N values (for different groups of fabrics) and to compare them in future works with the pilling grade of similar fabrics obtained using the standard method. In the future works analysis of the adequacy of both pilling assessment methods will be carried out with respect to alternative uses. In the future works this method will be completely automated to eliminate operator interference at important steps of the pilling assessment process.

Table 2. *The comparison of N value (as symbols) and pilling grade; x_1 to x_6 – values of percent rate of pilled surface, determined after experimental part.*

Value N	Grade	Description
$x_1 \leq N < x_2$	5	No change
$x_2 \leq N < x_3$	4	Slight surface fuzzing and/or partially formed pills.
$x_3 \leq N < x_4$	3	Moderate surface fuzzing and/or moderate pilling. Pills of varying size and density partially covering the specimen's surface.
$x_4 \leq N < x_5$	2	Distinct surface fuzzing and/or pilling. Pills of varying size and density covering a large proportion of the specimen.
$x_5 \leq N \leq x_6$	1	Dense surface fuzzing and/or severe pilling. Pills of varying size and density covering the whole of the specimen's surface.

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