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Prediction of Fuzz Fibers on Fabric Surface by Using Neural Network and Regression Analysis

Abstract
Fuzz on the fabric surface is very important for appearance quality, since it can lead to pilling and an unpleasant handle and appearance. Thus, it is important to predict the fuzz value on the fabric surface before producing the fabric. The amount of fuzz on the fabric surface, as has been determined by image processing techniques, can be predicted by two different methods, the Artificial Neural Network (ANN) and Regression Analysis. During knitting, the yarn used is abraded to an uncertain degree, depending on the knitting conditions and yarn properties, and this situation can lead to poor prediction results. However, it has been demonstrated that the prediction results obtained by Artificial Neural Networks look more promising than that of Regression Analyses.

Key words: *fabric fuzz, image processing, neural network, regression analyses, knitted fabrics, cotton, yarn.*

Introduction

Fuzz on the fabric surface is mostly undesirable because it degrades the appearance quality and feeling, and it can also lead to increased pilling. During the use of a fabric, pilling occurs in three stages, due to the fabric surface rubbing against other surfaces; fuzz formation, entanglement into pills and finally pill wear-off [18]. There are many studies related to the influence of yarn and fabric parameters on fuzz and pilling [1, 2, 4, 12, 18]. Millington pointed out that restricting the migration of surface fibre causes a decrease of the tendency to pilling; thus increasing the fabric tightness and yarn twist result in a decrease of the pilling formation [12]. Candan and Onal showed that the design of fabric and strength of fibres are also important for pilling. For example, lacoste fabric has a better performance against pilling than plain-knit fabric. An increase in the amount of synthetic fibre in the blend yarn leads to an increase of pilling tendency due to difficult fibre wear-off. Ring yarn generally shows worse pilling than open-end yarn due to its hairy and compact structure, which makes fibre wear-off difficult [4]. However, there is another study that contradicts this result; Alston pointed out that the pill resistance of the ring-spun fabric is better than the open-end yarn due to the poorer fibre orientation of open-end yarn which causes the fabric to produce more fuzz [1]. It has been also said that fabrics produced by an air-jet spun yarn have a lower tendency to pill than those made with open-end yarn, because the tightly wrapped structure of the air-jet yarn inhibits the formation of free fibre ends on the fabric surface, which are the primary reason for pilling [1, 2].

As seen from these studies, the initial amount of fuzz on the fabric surface is very important for the quality of appearance, the feeling and also for the potential of pilling during use. Thus, it is important to predict the fuzz on the fabric surface before production. It has been seen from the literature that predictions by Artificial Neural Networks (ANN) have more promising results compared to conventional prediction methods such as regression or correlation analyses, especially for non-linear and complex relationships among system variables [8 - 10, 16].

Even though several studies have been related to the prediction of several fabric and yarn parameters [5, 10, 11, 16], it is apparent that there is a great need for studies on the prediction of fuzz on the fabric surface. Therefore, in this study, the relationship of the fuzz on the fabric surface with several yarn and fabric parameters was examined by simple (bivariate) correlations. Then, the regression and Artificial Neural Network methods were used to predict the fuzz on the fabric surface and compared to each other.

Materials and methods

In this study, 43 samples of plain knitted fabrics produced with different cotton yarns and on different knitting machines were used. The predominant yarn and fabric parameters that might affect the fuzz on the fabric surface had to be selected and investigated in order to predict the levels of fuzz on the fabric surface. Therefore, the yarn hairiness, the yarn count and the fabric tightness factor were considered as affecting parameters. Before measuring the stitch length and taking a photo of the fuzz on the fabric surface, all fabrics were placed on a flat surface for one week in standard atmospheric conditions, 20 ± 2 °C, 65 ± 2% r.h. (dry relaxed fabrics). The stitch lengths were measured by unravelling a number of courses over 100 needles. The length of yarn was also measured and divided by 100 to obtain the stitch length. The average stitch lengths were calculated from ten readings [17]. The tightness factor was calculated by dividing the square root of yarn count in tex to the stitch length. The yarn hairiness has been measured by taking the average of three measurements of 50-metre yarn (S3 value) using a Zweigle apparatus. The ranges of yarn and fabric parameters are as follows: the range of yarn count is between 29.5 tex (Ne 20) and 19.7 tex (Ne 30); the range of hairiness of yarn (S3 value) is between 200 and 2500; the range of tightness factor is between 11 and 17; the range of wale density (wale/cm) is between 10 and 15; and the range of course density (course/cm) is between 11 and 25.

Fuzz on the fabric surface was measured by image analysis techniques [15]. In this method, erosion and dilation were used to segment the fabric surface from the fuzz structure (Figure 1). Then, the fabric surface image was subtracted from the original image to obtain an image that

***Figure 1.** Image of fabric surface.*

***Figure 2.** Fuzz on the fabric surface after image processing operations.*

contains only the fuzz structure. On this image, the fuzz is converted into white pixels by thresholding (Figure 2). The percentage of the white pixel occupied by fuzz in the image, called fuzz density, has been calculated to measure the fuzziness level of the fabric surface. Detailed information about this process is given in literature [15] by the author. For subjective measurement, twenty fabric samples whose fuzz density was measured by image analysis were ranked and rated by five experts, according to the relative severity of fuzziness, from least to most fuzzy. Then, the ranked fabrics were rated from 1 to 20. The correlation coefficient between the rating values obtained from subjective measurement and the results obtained from objective measurement was established as 0.9. More detailed information about the subjective measurement can be also obtained from the literature [15] by the author.

Correlation analysis

Due to the limited amount of data available for this research, 40 of the total 43 samples were used for regression analysis and training the ANN. The remaining 3 samples were reserved for checking the results obtained from both methods. The checking data were chosen among the low, moderate and high values of yarn hairiness. To see the relationship between the fuzz on the fabric surface and the yarn (yarn count and yarn hairiness) and the fabric parameters (tightness factor), bi-variate correlation analyses were applied. As seen from Table 1, there is only a strong correlation between yarn hairiness and fuzz on the fabric surface (the correlation is significant at a level of 0.01). Thus, the regression and ANN approaches were applied to find a prediction model between these two parameters.

***Table 1.** Correlation between fuzz on the fabric surface and yarn, fabric parameters; ** Correlation is significant at the level of 0.01 (2-tailed).*

Subject correlation	Yarn hairiness	Yarn count	Tightness factor
Fuzz on fabric surface	0.417**	-0.287	0.217

Regression analysis

Based on the relationships obtained from the bi-variate correlation analysis results (Table 1), levels of fuzz on the fabric surface was predicted by means of regression analysis. It is apparent that the correlation coeffcients (r) of linear and the second-power regression model (Equation 1 and Equation 2) are very low (Figure 3 and Figure 4). This may be due to the uncontrolled abrasion of yarn during knitting, depending on knitting conditions and yarn properties, such as knitting speed, contact surfaces on the machine, humidity, fibre properties, etc.

$$FF = 0.0001\ YH + 0.8378\ (r\text{: } 0.36) \quad (1)$$

$$FF = -\ 2\ 10^{-7}\ (YH)^{2} + 0.0008\ YH + + 0.5337\ (\text{r: } 0.61) \quad (2)$$

where:

FF - fuzz on the fabric surface,

YH - yarn hairiness,

r - the correlation coefficient.

Artificial Neural Networks (ANN) with back-propagation learning scheme

Artificial Neural Networks (ANN) are widely used in many applications such as pattern recognition, non-linear system identification, adaptive signal processing, etc. Artificial Neural Networks have also been applied to different textile problems such as classifying patterns or defects in textile textures, and predicting fabric parameters [3, 6, 7, 13, 14]. Among many Artificial Neural Network schemes, multi-layer feed-forward neural networks with back-propagation learning algorithms based on gradient descent have been widely used, since they offer unlimited approximation power for non-linear mappings. Therefore, in this study, an ANN was used with the back-

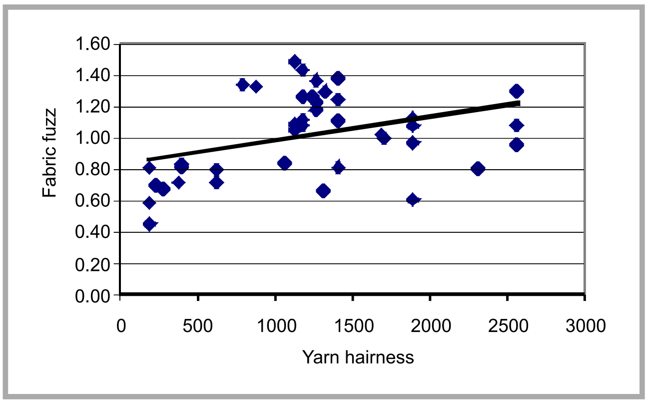

***Figure 3.** Result of linear model.*

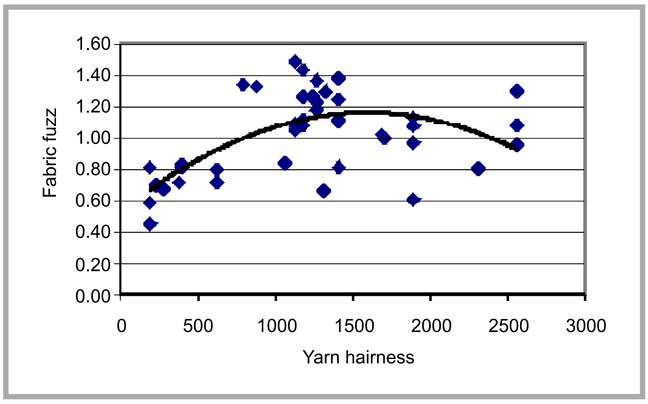

***Figure 4.** Result of second-power model.*

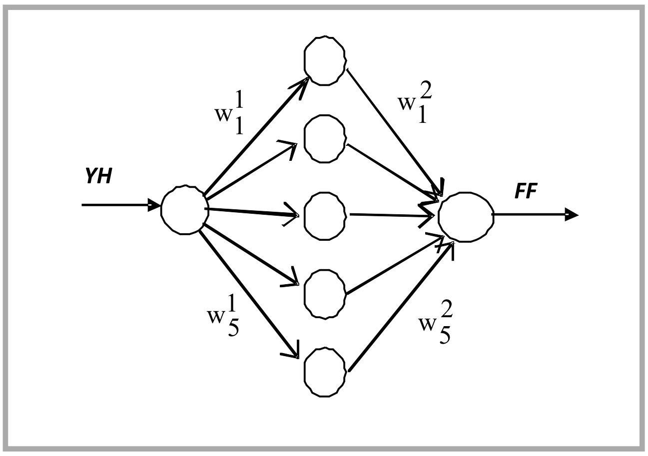

Figure 5. *Structure of ANN with 5 hidden neurons.*

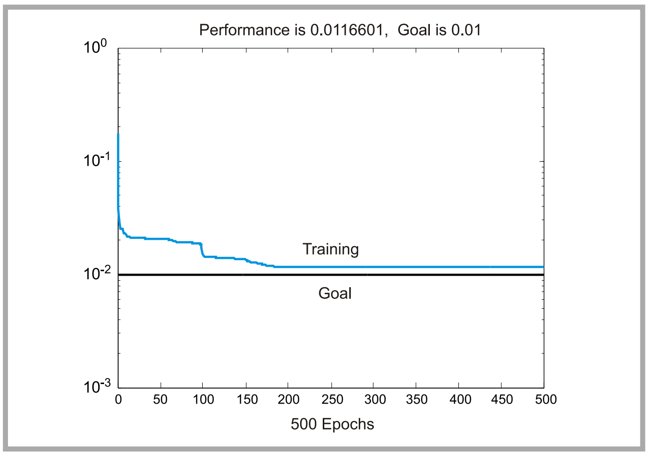

Figure 6. *Learning curve of the ANN model.*

propagation learning scheme to predict the hairiness of fabric. Extracted features from fabric images were fed to a pre-trained neural network for classification of the defects.

In the ANN structure, all the neurons in one layer are fully connected to neurons in the next layer. The error between the correct output and the ANN output is minimised using the back-propagation learning method. The structure of ANN is given in Figure 5, and the back-propagation algorithm is briefly explained in the following steps. More comprehensive information can be found in [8, 9]:

1. A training set containing known input (YH)-output (FF) pairs is defined.
2. All the weights, w_j^i, are arbitrarily assigned at the first iteration.
3. At each layer of the network, the outputs of the neurons are calculated in a forward direction.
4. At the output layer, the output of the ANN was compared to the given target values in the training set, resulting in an error term.
5. This error term is back-propagated through the network by updating the weights according to a desired algorithm. The program continues for a given number of iterations, or until an accepted error is achieved.

The yarn hairiness is fed to the ANN as input to predict the fuzz on the fabric surface at the output of the ANN. The structure of the ANN used in this research has two layers, consisting of 5 hidden neurons with logarithmic sigmoid activation functions at each layer and one neuron at the output layer with a linear activation function. Among many advanced learning algorithms, the Levenberg-Marguardt algorithm was preferred due to its fast convergence rate. The ANN was trained using 40 training samples, Even though the learning goal of 0.01 could not be reached, the training resulted in a mean square error of 0.0116 after 500 iterations. The learning curve is shown in Figure 6. After the learning process was completed, the ANN was tested using the 3 samples which were not included in the training set.

Results and conclusion

From the bi-variate correlation analysis, it was determined that there is a strong relationship between the fuzz on fabric surface and yarn hairiness (significant at 1% level). When the regression analysis is applied, the correlation coefficients are seen to be very low.

To be able to compare the results of all models, the sum of square of errors was calculated for both the testing and checking data (Table 2). Furthermore, the correlation coefficients between fabric fuzz and results obtained from models (linear regression, second-power regression and ANN) were calculated by using all 43 samples (Table 2).

When the values of the sum square total error (SSE, Table 2) and the correlation coefficient (CC, Table 2) are examined, it appears that the ANN gave better results than Equation 1 and Equation 2 for predicting levels of fuzz on the fabric surface. Hence it can be said that the ANN gives more promising results compared to regression models. The results including the ANN model were not found to be as good as expected, most probably due to the uncontrolled abrasion of yarn during knitting (depending on the knitting conditions and yarn properties). Our results are open to further development. We believe that if the quantity of training data is increased, the results of the ANN model can also be improved.

Table 2. *Sum of square of errors and correlation coefficients; SSET: sum square error for training data, SSEC: sum square error for checking data, SSE: sum square total error, CC: correlation coefficient between fabric fuzz and results obtained from models.*

Errors and correlation coefficient	Linear model	Second-order model	NN model
SSET	2.557	2.542	0.541
SSEC	0.159	0.077	0.131
SSE	2.716	2.619	0.672
CC	0.42	0.6	0.88

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References

1. *Alston P.V., 'Effect of Yarn Spinning System on Pill Resistance of Polyester/ Cotton Knit Fabrics', Textile Research Journal, 62(2), 105-108, (1992).*
2. *Alston P.V., 'Pilling of Sweatshirts That Are a 50/50 Blend of Polyester and Cotton', Textile Research Journal, 64(10), 592-596, (1994).*

3. Boyraz P., Yılmaz Ö., Ucar N., Ertuğrul Ş., 'Fault Detection in Knitted Structures Using Wavelet Analysis and Optimized Filter Design', The 9th Mechatronics Forum International Conference, 2004, August 30-September 1, pp. 449-454, Ankara, Turkey.
4. Candan C., Önal L., 'Dimensional, Pilling and Abrasion Properties of Weft Knits Made from Open-End and Ring Spun Yarns', Textile Research Journal, 72(2), 164-169, (2002).
5. Cheng L. and Adams D.L., 'Yarn Strength Prediction Using Neural Networks, Part I: Fibre Properties and Yarn Strength Relationship', Textile Research Journal, 65(9), 495-500 (1995).
6. Chen P., Liang T., Yau H., Sun, W., Wang, N., Lin, H., Lian, R., 'Classifying Textile Faults with a Back-Propagation Network using Power Spectra', Textile Research Journal, 68(2), 121-126,(1998).
7. Calı S., Ertuğrul Ş., Ucar N., 'Fault Detection and Classification in Knitted Structures Using Fourier Analysis and Neural Networks', The 9th Mechatronics Forum International Conference, 2004, August 30-September 1, pp. 445-448, Ankara, Turkey.
8. Dayhoff J.E., Neural Network Architectures: An Introduction, Van Nostrand Reinhold, USA, 1990.
9. Fu L., Neural Networks in Computer Intelligence, McGraw-Hill, Singapore, 1994.
10. Ertuğrul Ş., Ucar N., 'Prediction of Bursting Strength of Plain Knitted Fabrics Using Intelligent Techniques', Textile Research Journal,70(10), 845-851,(2000).
11. Ertuğrul Ş., Uçar N., 'Prediction of Yarn Properties using Adaptive Neuro-Fuzzy Inferencing System', 5th International Conf. on Mechatronics Design and Modeling, September 5-7, 2001, Konya, Turkey.
12. Millington, K., 'Using Ultraviolet Radiation to Reduce Pilling of Knitted Wool and Cotton', Textile Research Journal, 68(6), 413-421, (1998).
13. Tilocca A., Borzone P., Carosio S., Durante A., 'Detecting Fabric Defects with a Neural Network Using Two Kinds of Optical Patterns', Textile Research Jourrnal, 72(6), 545-550, (2002).
14. Tsai I.S., Lin C., Lin J., 'Applying an Artificial Neural Network to Pattern Recognition in Fabric Defects', Textile Research Journal, 65(3), 123-130,(1995).
15. Ucar N., Boyraz P., Measurement of Fuzz Fibres on Fabric Surface Using Image Analysis Methods, Fibres and Polymers, 6(1), 79-81,(2005).
16. Ucar N., Ertuğrul Ş, 'Prediction Of Circular Knitting Machine Parameters for Cotton Plain Fabrics by Means of Conventional and Neuro-Fuzzy Methods', Textile Research Journal 72(4),361-366, (2002).
17. Ucar N., Karakas H., 'Effect of Lyocell Blend Yarn and Pile Type on the Properties of Pile Loop Knit Fabrics', Textile Research Journal, 75(4), 352-356, (2005).
18. Williams V.A., 'A Kinetic Model for Pilling of Wool Knitwear', Textile Research Journal, 55(5), 312-320, (1985).

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