Identification and Classification of Spliced Wool Combed Yarn Joints by Artificial Neural Networks

Abstract

A new artificial neural network (ANN) has been created, similar to the ADALINE-type network, with linear activation function and bubble error sorting, designed to recognise and classify pneumatically-spliced yarn joints. In the second part of the article, the effectiveness of recognition and classification of the proposed ANN will be presented.

Key words: spliced yarn joints, wool combed yarn, yarn identification, joint classification.

Introduction

Precise measurements of physical properties of fibres such as fibre staple length, linear mass, strength of fibres, etc. help to decrease spinning costs and to determine more precisely how to set the machines for the production. However, controlling technological processes involves a large number of manual operations which as a rule are very time-consuming. The demand for automatic methods and the benefits from instrumental and computer techniques result from the requirements of modern economics. The introduction of measure-control apparatuses was the first step towards decreasing the problems connected with performing troublesome tests.

There are, however, some laboratory tests, e.g. those applied to determine non-measurable features of semi-manufactured or end products, which cannot be performed by means of measuring devices. The estimation of the features is usually carried out organoleptically (visually or by touch), and has many disadvantages because it is slow and subjective, and it involves expensive and long-lasting training of experts. Thus it became necessary to find methods which could eliminate all these drawbacks. To a large extent digital techniques of image processing and automatic techniques to perform analyses can successfully be applied to solve the problems.

In recent years intensive development of artificial intelligence (AI) methods has been observed, leading to the design of computer expert systems to perform the tasks previously carried out by a man. From among many methods of AI, artificial neural networks (ANNs) can be used to construct computer systems, which can replace human experts. They can create the basis for an inference mechanism as effective as deterministic formulas based on classic two-dimensional logic. The advantage of ANNs over classic algorithmic methods lies in the fact that, with the classic methods, it is necessary to know the full model of a procedure, which would enable a deterministic rule of inference to be formulated.

On the other hand, ANNs are ‘self-programming’, i.e. they can design a program using the data fed into the system. ANNs can process the information, and perform such tasks as [1]:

§ matching defected or retrieved input with the closest pattern stored,

§ matching two patterns, diagnosis, analysis,

§ classification, i.e. dividing the input into classes or categories,

§ recognition, that is to say, input classification, even though the input corresponds with no patterns stored, etc.

ANNs have found application in many fields of science, including textile and clothing industry. ANNs can also be used to recognise and classify unknotted spliced joints of yarns, as performed most often during winding operations on automatic winders. Among the papers on the subject, Cybulska’s studies [2] well confirm the aptness of ANNs for this purpose. The author assessed the yarn structure by evaluating its basic parameters, such as linear mass, hairiness and twist number, by means of image analysis as well as mathematical methods. Such a combination of methods resulted in the obtaining of the digital characteristics of a yarn structure at each point of the yarn length, as well as acceptable mean values and irregularity evaluation of structural parameters for the whole length of the yarn. It can also be applied to the yarn section which includes unknotted spliced joints.

An important aspect of the fibre-to-yarn production process is the quality of the resulting yarn, which should obviously have optimum product characteristics and minimum faults, such as thins, thicks, neps, etc. [3]. Weak places occurring in the yarn caused by the narrowing of yarn sections should be eliminated to avoid the danger of breakages. Randomly-occurring yarn breakages very often cause thread breakages during weaving or knitting operations. Ring-spun yarns, in comparison with open-end rotor yarns, reveal many more faults caused by small cheese dimensions. Besides, as a result of joining operations on winding machines, they may have as many as 40-60 faults/per 1 kg of yarn [3]. Thus, the assessment and improvement of yarn quality cannot be confined only to the determination of the mean values of individual parameters. Recently, unknotted spliced joints have successfully been applied to solve the problem of yarn breakages.

The correct splicing of broken yarn ends depends on many factors, but most important is how yarn ends are prepared. However, obtaining an ‘ideal’ joint is practically impossible. The choice of the most favourable settings, i.e. the best technological parameters of a splicing device, is the task of engineers who should possess specific knowledge of the subject. No objective and effective methods have yet been found, which could not only optimise technological settings of a splicing device, but also simultaneously classify spliced yarn joints. The assessment of the relationship between the non-measurable features of spliced yarn joints and the strength parameters of the joints is also significant. The strength of spliced yarns is defined as a coefficient of strength effectiveness [11].

Quite frequently there are significant discrepancies between the appearance of spliced joints and their strength properties, because a ‘good-looking’ spliced joint does not necessarily fulfil strength criteria, or vice versa. Sometimes, yarns characterised by a high coefficient of strength effectiveness can be assessed as ‘poor’ considering their appearance. Therefore it is very important to work out and find compromise limits in this respect. In the studies carried out so far by Bissman [5], Gebald [6], Kaushiik, Sharma, Hari [7-10] and by FrontczakWasiak & Snycerski [11], Machnio and Drobina [12-13] in Poland, only physical properties and appearance of the obtained spliced joints of yarns have been assessed. However, some recent publications deal with optimising the work of splicing devices. Cheng and Lam [14- 15] in South Korea, and Lewandowski & Drobina [16] in Poland have made the first attempts in this respect. Cheng and Lam tested spliced cotton yarns and blends of cotton (65%) and polyester (35%) by means of a Jointair 114 splicing device, produced by MESDAN (Italy). Using a Jointair 4941 (also produced by MESDAN), Lewandowski & Drobina [16] tested spliced wool-combed yarns. Taking a step forward, the authors suggested that the problem of recognition and classification of unknotted, pneumatically-spliced joints of yarns can be successfully solved by means of ANNs.

Following the earlier investigation, Cheng and Lam [17] quite independently determined and compared the physical properties of pneumatically-spliced cotton yarns with the help of both regression analysis and ANNs. Cheng and Lam’s studies [17] can be considered as pioneering because they first used ANNs to predict the physical properties of pneumatically-spliced yarns.

In this paper, an attempt has been made to design our own ANN, similar to ADALINE, with linear activation function and bubble error sorting used to recognise and classify pneumatically-spliced wool-combed yarn joints.

■ Theoretical

In most cases, the selection of technological parameters of a splicing device is based on the subjective, organoleptic evaluation of the spliced yarn joints obtained, considering their appearance alone, which depends on the technician’s experience. However, no effective and reliable methods have so far been elaborated which could optimise the work of a splicing device and classify spliced yarn joints. It can be assumed that the problems cannot be solved using only traditional methods. Thus, in this study the authors have designed and made use of an artificial neural network for the purpose of recognising and classifying spliced yarn joints.

Presentation of the problem

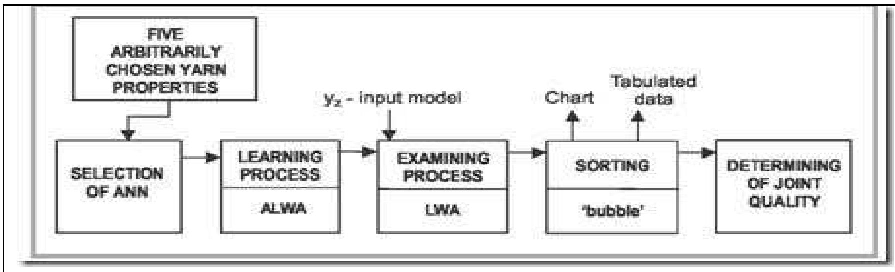
In order to recognise and classify pneumatically-spliced unknotted yarn joints obtained after winding operations, we used a model of a single neuron as the basis for the calculations of the required data in the form of weights of connections to describe all the samples considered. The applied neuron is called ADALINE, which stands for Adaptive Linear Element. We created a database of all the joints, and the numbered neurons corresponded to the joints. The outputs of all the neurons located in the database of unknotted joints were compared with the assigned model, which made it possible to determine all the neurons’ errors and to sort them in ascending order.

The neuron with the minimum error value was recognised as the ‘winner’ [18]. In the elaborated procedure, if none of the neurons meets the criteria of the model, then the neuron classified with the minimum error, or in other words that with the minimum deviation from the assigned signal, will be taken into consideration [19]. The iteration process is continued until the appropriate neuron is classified and located on the three-degree quality scale for unknotted yarn joints.

Presentation of algorithm descriptors The procedure applied which describes this process included the following steps:

I. Collecting specimens of unknotted joints and placing them in the database:
determining five features for each of 1250 specimens,
creating a three-degree quality scale and establishing the rank of importance.
II. Selecting an artificial neural network to recognise and classify unknotted joints.
III. Applying an adaptive linear weighing adder (ALWA) as a model for the learning process performed by an artificial neural network of the ADALINE type.
IV. Applying a linear weighing adder (LWA) as a model for examining the effectiveness of the ANN.
V. Using ‘bubble’ sorting [19] as an algorithm serving to sort the errors in ascending order from the database of unknotted yarn joints.
VI. Determining the quality of spliced unknotted yarn joints on the basis of ‘criteria’ analysis of the sorted neurons.

For all the analysed unknotted joints, the described procedure enables the results to be presented in the form of diagrams and tabulated data. A simplified chart of the investigation procedure is shown in Figure 1. Particular blocks of the research model were carried out in successive steps of the procedure.



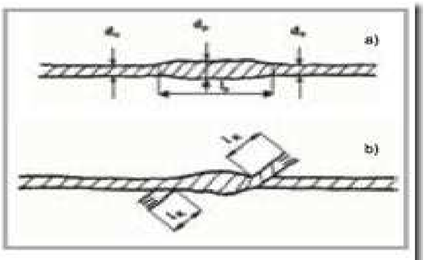


Figure 2. Longitudinal view of: a - spliced yarn joint revealing the geometric irregularities of yarn, b - spliced yarn showing the joint with unspliced yarn ends.

Methodology for Determining Spliced Yarn Properties and Creating a Rank List

Step I – determining yarn properties

Determining strength parameters

An Instron 5544 tensile tester was used to test the breaking strength parameters of both the parent and spliced yarn joints. The specimen length was set to 500 mm. The specimens were mounted in the clamps in such a way that the spliced joint was in the middle of a clamp distance in the tensile tester. In our study, we took into account only those measurements which refer to cases when the breakage of the spliced yarn was located exactly in the place of the joint. On the basis of the results, we determined:

§ the breaking forces of the parent and spliced yarn joints Fr, Frs [cN] respectively,

§ the relative breaking elongation of the spliced yarn joints Ers [%],

§ the breaking tenacity of the parent and spliced yarns Wt, Wts [cN/tex] respectively.

In order to indicate the differences between the strength properties of the parent and the spliced yarns, the coefficient of joint effectiveness

$$\eta_{w} = \frac{Wt_{s}}{Wt} \cdot 100[\%]$$

was also determined.

Determining geometric characteristics In order to investigate the geometric characteristics of spliced yarn joints, an image analysis of the yarn joints was performed by means of a Nikon-800 video camera (Panasonic) and a Steddy-T type stereoscope microscope (CETI), as well as a computer assembly using the Micro-scan 1.3 program.

Considering the appearance and the microphotograph images of the spliced joints, we determined:

§ the lengths of yarn spliced joints lp,

§ the crosswise dimensions of the parent yarns dn [mm],

§ the crosswise dimensions of the spliced yarns dp [mm], § the length of yarn ends unspliced in the linkage lk [mm], as shown in Figure 2.

Assessing the non-measurable features of spliced yarn joints

Considering the non-measurable features, such as fibre tangling in the place of joining Ta and teaselling Te, the yarn joints were classified into three categories:

a) with a low degree of tangling (Ta=0) and teaselling (Te=0),
b) with a medium degree of tangling (Ta=1) and teaselling (Te=1),
c) with a high degree of tangling (Ta=2) and teaselling (Te=2).

Both the image of tangling and the image of teaselling were assessed by 10 people with or without practical experience, and the following three-degree quality scale was established for the spliced yarn joints: 'good', 'medium' and 'poor', respectively.
Teaselling is characterised by the intensity of unspliced yarn ends not joined with the yarn core along the whole length of the joint.
Tangling means a lack of proper orientation of the elementary fibres in a joint. Joints characterised by a low degree of tangling (Ta=0) have a structure similar to that of a yarn without a joint, a visible and regular screw line, and good orientation of single elementary fibres in a joint.

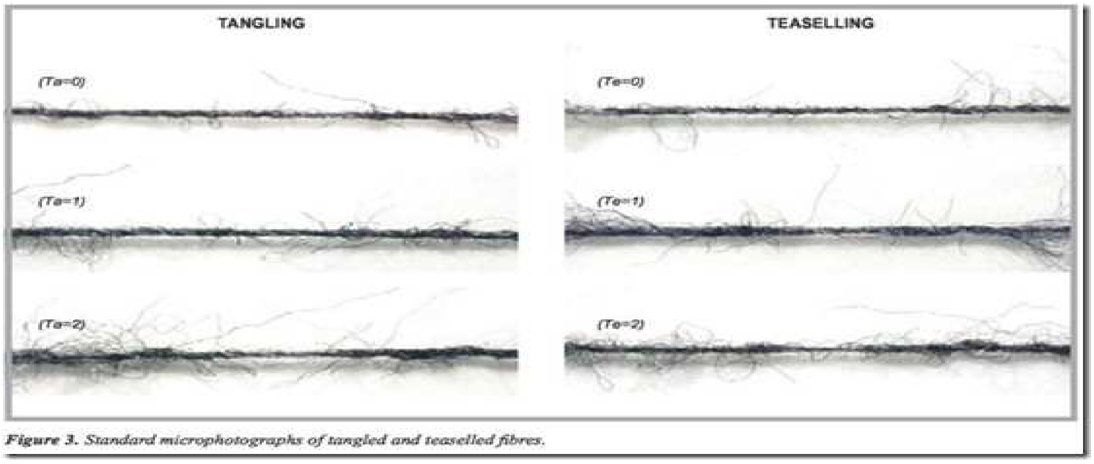


Figure 3. Standard microphotographs of tangled and teaselled fibres.

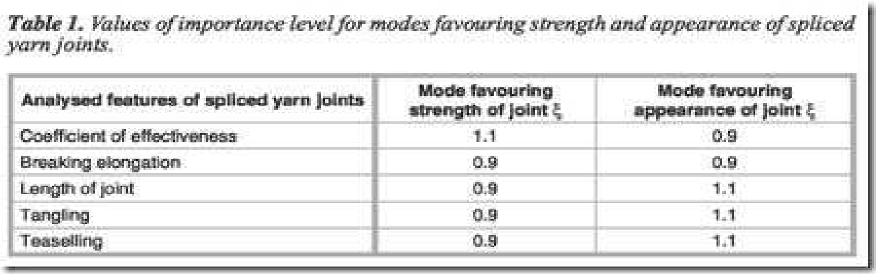


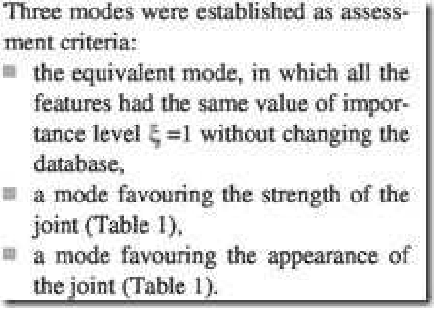
Table 1. Values of importance level for modes favouring strength and appearance of spliced yarn joints.

Analysed features of spliced yarn joints	Mode favouring strength of joint ξ	Mode favouring appearance of joint ξ
Coefficient of effectiveness	1.1	0.9
Breaking elongation	0.9	0.9
Length of joint	0.9	1.1
Tangling	0.9	1.1
Teaselling	0.9	1.1

Joints with a medium degree of tangling (Ta=1) differ slightly from yarns without joints. The elementary fibres in the joint are badly oriented, and the joint itself is quite big (voluminous) with noticeably protruding fibres.
Joints with a high degree of tangling (Ta=2) possess no screw line, and are characterised by increased volume, large gaps (clearings) in the structure, a large number of protruding unjoined fibres, a loose structure and a lack of jams between the fibres, which is characteristic of yarns without joints.
Another group of joint faults are thins, caused by too large twists, or, in other words, by overtwisting. Although a joint with thins looks good along its whole length, it is disqualified because it is too weak and has very low mechanical strength.
Standard microphotographs of fibres tangled and teaselled in the place of joining are shown in Figure 3. A microphotograph of a joint containing thins is shown in Figure 4.

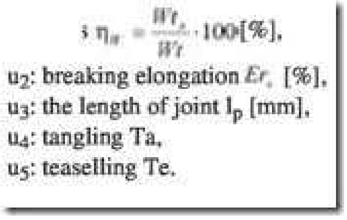
Creating rank list

In order to classify and evaluate the quality of spliced yarn joints, the following strength parameters, geometric characteristics and non-measurable features of the joints were taken into account:
u1: the coefficient of joint effective-



Three modes were established as assessment criteria:

- the equivalent mode, in which all the features had the same value of importance level ξ =1 without changing the database,
- a mode favouring the strength of the joint (Table 1),
- a mode favouring the appearance of the joint (Table 1).



; $\eta_w = \frac{Wr_z}{Wr} \cdot 100[\%]$,

u_2: breaking elongation Er_z [%],

u_3: the length of joint l_p [mm],

u_4: tangling Ta,

u_5: teaselling Te.

The database which completes the features are fed by information from a ‘p’ number (c) of specimen, i.e. learning sequences (c∈ [1...p]), each them consisting of five features characterising each specimen (u1 ... u5).

Step II - selection of the ANN

From among different kinds of ANN such as the feed-forward network Multi Layer Perceptron (MLP), the probabilistic neural network (PNN), the Kohonen network, the Hopfield network, etc. we chose a single neuron of the ADALINEtype ANN with a linear activation function, which enabled the neuron signals to be obtained in the form of real numbers. If another activation function were applied, the output signal would take the form of a bipolar function as a binary code, and it would be impossible to make the various comparisons showing how the assigned sample was correlated with the joints obtained. It would also exclude the occurrence of numerous other significant

samples in the general population, and finally it would be impossible to classify the unknotted spliced yarn joints.

Step III - learning process

In the learning process performed by the ANN, the Delta rule was applied, which assumes learning with a ‘teacher’. According to this principle, each neuron first receives the determined signals (from the network, or from other neurons placed on the previously created levels of data processing), and then creates its own output signal utilising the formerly acquired knowledge of coefficient values of weights, and possibly of the threshold value.

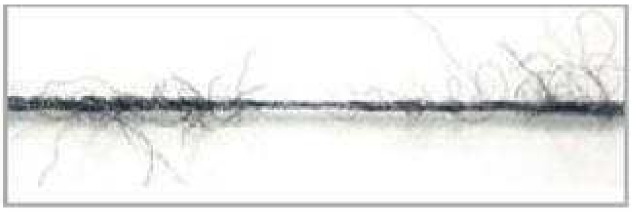


Figure 4. Micro-photography of a joint containing thins.

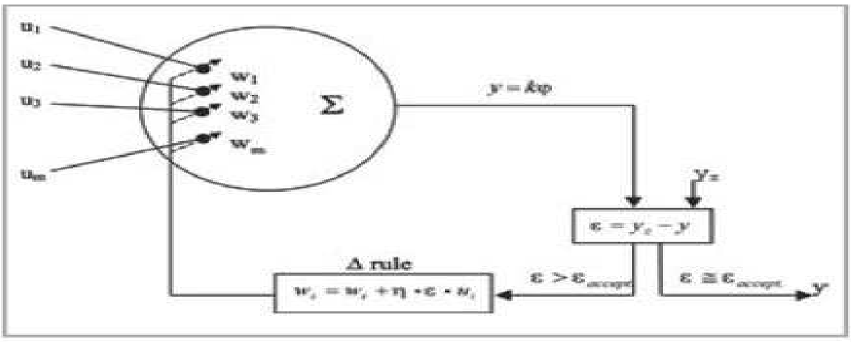


Figure 5. Scheme of ALWA performing the controlled learning process of an artificial neural network using the Delta rule; u_1-u_m - features characterising a specimen i∈ [1...m], w_1-w_m - neuron's memory, i.e. its weight, Σ - adder, φ - activation function, y - value of neuron output signal, k - empirically determined coefficient, y_z - value of standard signal, ε - relative error of values generated by neurons with Delta rule as applied in the learning process, $\varepsilon_{accept.}$ - acceptable error, arbitrarily establishing exactness, determined by the number of decimal places, η - learning rate.

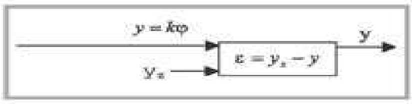


Figure 6. Model of LWA performing the processes of examining ADALINE artificial neural network. The applied symbols stand for the same values as in Figure 5.

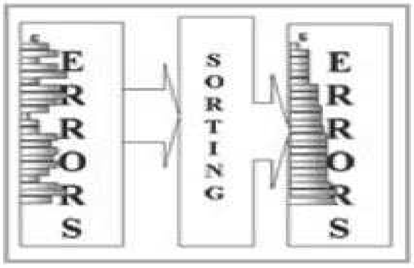


Figure 7. Model of 'bubble' error sorting process; ε - error values [19].

The value of the output signal established by the neuron at each stage of the learning process is compared with the model value determined by the 'teacher'. If these two values vary, then the difference between them is calculated and denoted by the Greek letter 6, (which gave the name to the method). The Delta signal is used by the neuron for correcting its weight coefficients, and possibly the threshold. If the value of an error made by a neuron is known, then it is easy to predict how its weight will change. In practice, a well-trained network stops the learning process when the errors are small, causing only insignificant weight corrections. The flowchart of ALWA, the model performing the controlled learning process of the ADALINE ANN, is shown in Figure 5.

Step IV - examining process

A shortened flowchart of the LWA model which performs the process of examining the ADALINE-type artificial neural network with linear activation function, is presented in Figure 6. It should be noted that while examining the network, no corrections of neuron weights were made, because the learning process of the network was based on the AWLA model.

Step V - sorting process

In order to sort the errors in the growing order of their values, 'bubble' sorting was applied with the authors' own interpretation of the algorithm. However, other algorithms of sorting numerical values are also known [19], including sorting by selection, sorting by insertion, and Shell's sorting. A block chart of 'bubble' sorting [19], as an algorithm classifying errors in the growing sequence from the database of stored unknotted spliced joints, is shown in Figure 7.

Step VI - quality determination

A block scheme for determning the quality of spliced unknotted yarn joints on the basis of the criteria analysis of the sorted neurons is shown in Figure 8.

In the second part of this article, the effectiveness of recognising and classifying the proposed ANN, as well as the conclusions, will be presented.

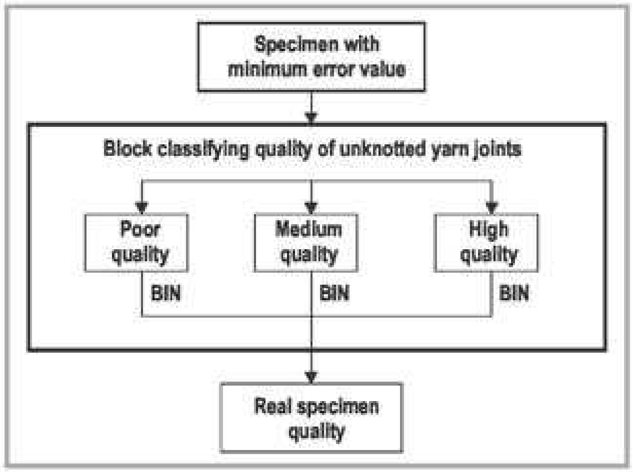


Figure 8. Classification chart of unknotted yarn joints; BIN - binary values 0 or 1.