

Neural Network Classification of the Unknotted Joints of Yarn Ends

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Abstract

The artificial neural network elaborated in this research enabled to recognise and multi-criterially classify the unknotted joints of yarn ends. Worsted weaving woollen yarn with a linear mass of 15 tex was used as an example. A 10-step quality scale was applied in order to increase the accuracy of recognition and classification of joints. Such a neural network design can be applied for the quality classification of such joints, as well as in other fields of the textile industry.

Key words: neural network, classification scale, unknotted joints, spliced yarn ends, wool yarn.

Introduction

The demand for the production of yarns free of defects and their elimination through the unknotted spliced ends of yarns has increased with the rising speeds of spinning machines. Such joints are “inserted” as segments replacing the broken ends of yarns or replacing damaged segments of yarns whose properties do not meet the quality standards imposed *a priori* by the purification parameters of electro-capacitive purifiers. The unknotted joints of yarn ends are classified as textile objects which may cause great disturbances, making it hard to find optimal settings for the splicing device creating such joints. In view of this, it is extremely important to find and elaborate alternative methods which enable to classify such joints. In fact, there are just a few literature references concerning the classification mentioned above [1 - 3]. An important example is article [3], in which a method of competitive learning based on the LBG algorithm was used to detect the joints, while to classify them, the algorithm of Dynamic Time Warping (DTW) was utilised. However, no information was found about the optimisation of splicing devices used for the unknotted joints of yarn ends, nor about the quality evaluation of the unknotted spliced ends of yarns with the use of neural network classification. The most important features and parameters that decide about not only the quality of end-products but also about the costs of the production process are appearance, strength, abrasion resist-

ance and the bending resistance of yarns. In the conditions of a real technological process, research should not only be based on the average values of particular physical properties, but all possible cases should be taken into consideration. From the point of view of a technological process, the most dangerous are rare errors in the form of thin places, thick places, neps, and other faults [6].

The article presents a neural network developed by the author based on the ADALINE neural network, which enables to recognise and classify the unknotted joints of yarn ends.

Definitions: classification, statistical classification, statistical classifiers and neural classification

Generally, classification can be divided into a taxonomical and statistical one. Statistical classification is of great importance for classification of the unknotted spliced ends of yarns. In a traditional depiction the term ‘classifier’, referring to classification, means a person who deals with the classification process. In a statistical depiction classifiers can be divided into the following: linear classifiers, naive Bayes classifiers, perceptron, k-nearest neighbours algorithm, decision trees and probabilistic Bayesian networks.

There is also a neural classification in which artificial neural networks (realising the classification tasks) enable to attribute each case represented by particular input data to one of the possible classes selected. Such a neural network is responsible for estimation of the probability of membership to a particular class [7]. To realise classification tasks, the most useful are artificial neural networks of multilayered perceptron (MLP),

networks of radial base networks (RBF), Kohonen networks, probabilistic networks and linear networks [7].

Elaboration of the architecture and topology of artificial neural networks for classification of the unknotted joints of yarn ends

The following algorithm for neural classification of the unknotted spliced ends of yarns was proposed (*Figure 1*), taking into consideration information concerning the characteristics of textile objects, including the classification of textile objects, the characteristics (additive and non-additive) and standards of textile quantities [5, 8], as well as drawing from own experience.

Step I. Realisation of an experimental plan, conducting experimental investigations, creating a database and determining the number of features for each unknotted spliced joint of yarn ends

While planning the experiment and its realisation, an analysis of the state of art was conducted concerning the influence of particular settings of the Jointair 4941 device [11] on the properties of the spliced joints of yarn ends. It was noted that the appearance and properties of the unknotted spliced joints of yarn ends produced by this device can be shaped using the following four input variables:

- **Time of splicing cycle (t_A)** - controlled by the time of air blow-in on the spliced ends of yarns. $t_A = 0$ means the shortest time of the blow-in, while $t_A = 5$ means the longest time.
- **Length of spliced ends of yarn (l_B)**
- **Volume of blow-in air during the splicing cycle (V_C)**, where $V_C = 0$ means a low volume of air used – 0.6

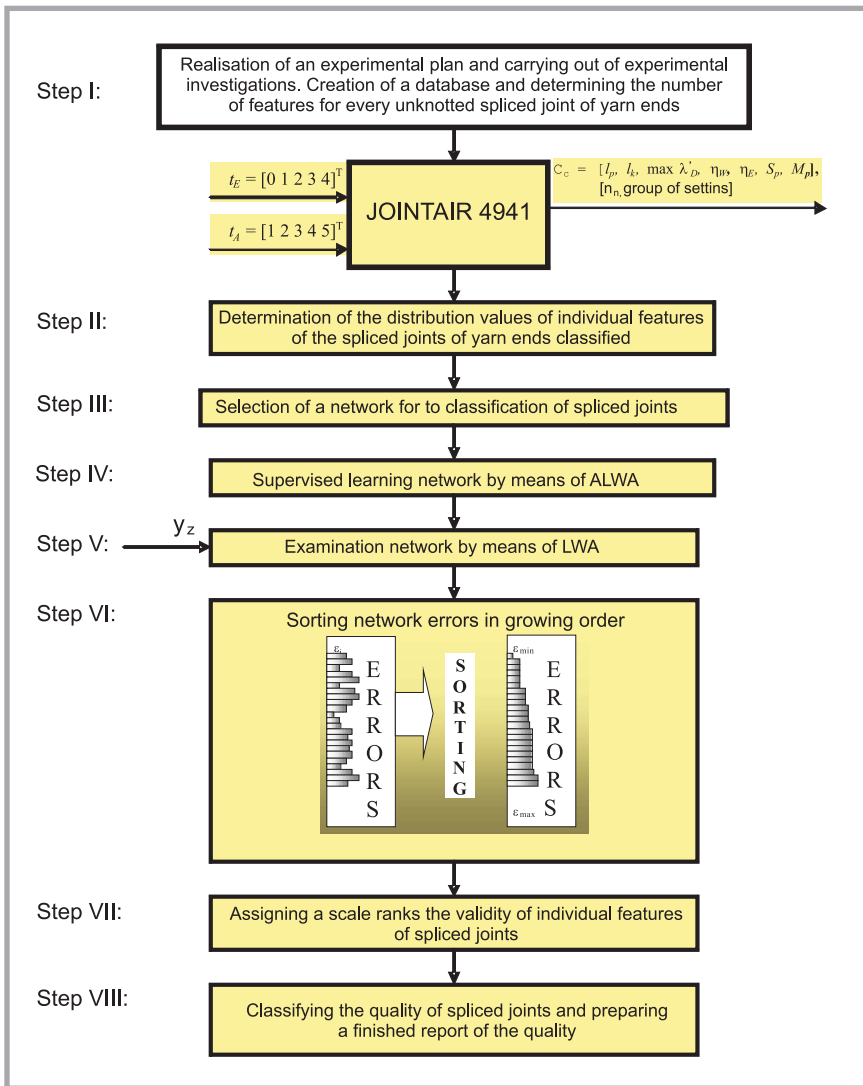


Figure 1. Algorithm for the classification of unknotted spliced ends of yarns; where: $t_E = [0\ 1\ 2\ 3\ 4]^T$ – input vector of the time of untwisting yarn ends for splicing in a device preparing the ends of yarns, $t_A = [1\ 2\ 3\ 4\ 5]^T$ – input vector of the splicing time, c – number of learning sequences, $c \in [1...p]$, p – the last learning sequence, l_p – length of the joint, l_k – length of fibres and yarn ends protruding from the joint, $\max \lambda_D$ – maximum increase in the crosswise dimension of the joint, η_W – coefficient of spliced strength retained, η_E – coefficient of spliced breaking elongation retained, S_p – tangling, M_p – teaseling, ALWA – Adaptive Linear Weighted Adder; LWA – Linear Weighted Adder; and y_z – defined model signal arbitrarily sent, characterising spliced joints.

1 for 1 joint, $V_c = 6$ means a high volume – 3.0 l for 1 joint

- **Time of yarn end preparation (t_E)** – the untwisting of yarn ends in a device, where $t_E = 0$ means without blow-in, $t_E = 1$ – short-lasting time of untwisting yarn ends, $t_E = 2, 3, 4$ – average time of untwisting yarn ends and $t_E = 5$ – long-lasting time of untwisting.

The MESDAN company [11] suggests only the kind of splicing chamber, number of twists and the type of cover for the splicing chamber for particular kinds of yarn (**Figure 2**), but no information is given about the setting values - t_A , l_B , V_c and t_E recommended for this

device. Thus, it is possible to consider a general input vector in the form of

$$X = [V_c, l_B, t_A, t_E]^T \quad (1)$$

Among the work parameters of the device analysed, the volume of blow-in during the splicing cycle was assumed as a constant value, controlled by parameter V_c , revealing that the correct joint for the spliced ends of yarn can be evaluated by organoleptic tests during the process of splicing. According to the producer's recommendations [11], the regulation of setting V_c can be undertaken for high twisted yarns only. Therefore, it was assumed that the setting equals $V_c = 0.6$ l/joint.

Carrying out the investigations using a function of 3 settings,

$$X = [l_B, t_A, t_E]^T \quad (2)$$

is possible but much more expensive, having no economic reason. One should keep in mind that every forced interruption of the continuity of the fibre stream, in order to form an unknotted joint, significantly decreases the life of the splicing device. With a high number of repetitions, this factor becomes even more significant. Therefore, in all the experiments it was assumed that the length of spliced ends equals $l_B = 4$.

Finally, the diversification of physical properties of the unknotted joints of yarn ends was obtained by simultaneous changes in the time of unwinding yarn ends for splicing (t_E) and by changes in the time of the splicing cycle (t_A). The data was analysed according to the 5×5 plan of the experiment.

Characteristics of the experiment

The physical properties of worsted woollen yarn and those of yarn used for spliced joints are presented in **Table 1** (see page 40).

Dyed worsted weaving woollen yarn with a linear mass of 15 tex and number of twist - 770Z was the subject of this research. It was produced on a FIOMAX 2000 ring spinning machine, made by SUESSEN. The unknotted joints of worsted woollen yarn ends (15 tex, 770Z) were made on a JOINTAIR 4941 splicer, produced by the MESDAN company, integrated with an automatic winding machine - ESPERO M, produced by SAVIO. The linear mass and number of twist proposed are typical for a worsted

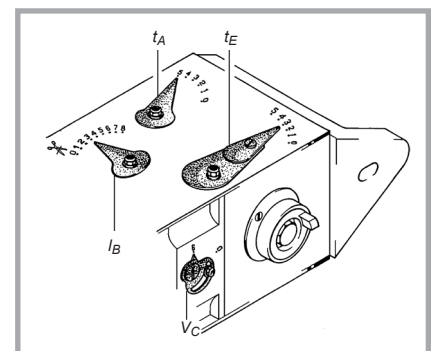


Figure 2. Chamber of the JOINTAIR 4941 splicing device produced by MESDAN, controlling splicing chamber 5AW, with a chamber cover -110 and preparation device - Z20/S20 [11].

Table 1. Physical properties of fibres, worsted woollen yarn and yarn used for spliced joints.

| Parameters analysed – fibres and tops | Unit | Value |
|---|--------|-------|
| Nominal diameter of fibres | µm | 19.0 |
| Average length of fibres | mm | 65 |
| Maximum length of fibres | mm | 134 |
| Content of fibres shorter than 40 mm | % | 21.6 |
| Parameters analysed - yarn | Unit | Value |
| Linear mass - Tf_p | tex | 15 |
| Direction and number of twist - S | rev/m | Z770 |
| Breaking force – F_r | cN | 75.48 |
| Tenacity – W_t | cN/tex | 5.03 |
| Coefficient of variation of the breaking force – $V(F_r)$ | % | 17.62 |
| Relative elongation at break – E_r | % | 7.48 |
| Coefficient of variation of the linear mass – $CV_{8\text{mm}}$ | % | 20.58 |

yarn spinning mill in the range of thin weaving yarns.

For each combination of input variables (t_{A_i} , t_{E_i}) 50 joints were formed, creating a database consisting of 1250 experiments. At the same time they were the vectors of the output signals - y_z . For each joint 7 features were determined:

$$C_c = [l_p, l_k, \max \lambda'_D, \eta_W, \eta_E, S_p, M_p];$$

[n_p , group of settings of the splicing device] (3)

An unknotted spliced joint, with its characteristic geometrical dimensions marked, is presented in **Figure 3**.

For example, the neuron number 310 stands for the 275th sample of the joint, made using a slicing device (A2E1), collected during the experiment. Such a joint corresponds to the 310th feature of additive and non-additive quantities, being at the same time a database for the algorithm of neural classification. Such a design of neural classification enables to optimise a splicing device considering each feature separately. For instance, a neuron carrying information about the appearance of a joint far from the standard can correspond to an unknotted joint of yarn ends meeting the highest strength requirements.

Step 2. Value distribution of particular features of classified unknotted joints of yarn ends

In order to evaluate the characteristics of joints, a scaling method was used that formulates all characteristics of the

joints of yarn ends, which are evaluated separately into one value expressing the general quality of the joint investigated. The scales of steps differ from each other in the degree of their development, construction and connection with quality choices affecting the results obtained. In order to select a 0 - 9 scale, characteristic properties significant for the quality of the textile end-product were taken into consideration. While defining the quality levels of each feature selected, the configuration of the grading scale was verified by conducting multiple experimental evaluations of the feature investigated. The evaluations were made by teams of 7 experts, who expressed their opinions on the correctness of the definition, suggested possible corrections and assessed the coefficient of weight of particular features, taking into consideration the importance of a given feature for the general evaluation of unknotted joints of yarn ends. In the final stage an analysis of the values of particular features characterising the joint was conducted in order to improve the final evaluation. To check the percentage value corresponding with the value of the particular feature, the following dependence was applied:

$$Share_i = \frac{Step_i \cdot Max_c}{100}, \quad (4)$$

where:
 i – value of the step informing by which amount the share is calculated

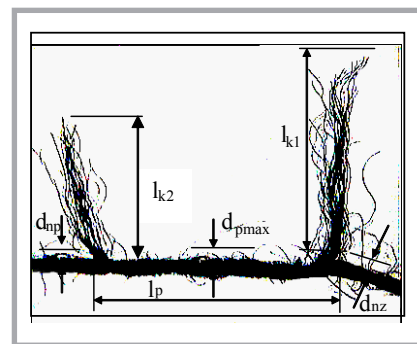


Figure 3. Unknotted spliced joint with its characteristic dimensions marked [5].

c – feature
 Max_c – maximum value of the particular feature.

With the shares known, it is possible to calculate the number of samples within every range. The number of grades of quality choices was established in the same way as grouping the results using the stemplot method [9, 10]. Before dividing into grades of quality, its number was taken into consideration. The number of grades, likewise the number of classes, cannot be too high as it makes it difficult to read the results and to draw conclusions. However, a low number decreases the accuracy of results. The optimal number of classes to include should be within the range of 10 - 25, and it cannot be lower than 8 or higher than 30 [10]. Following the instructions mentioned

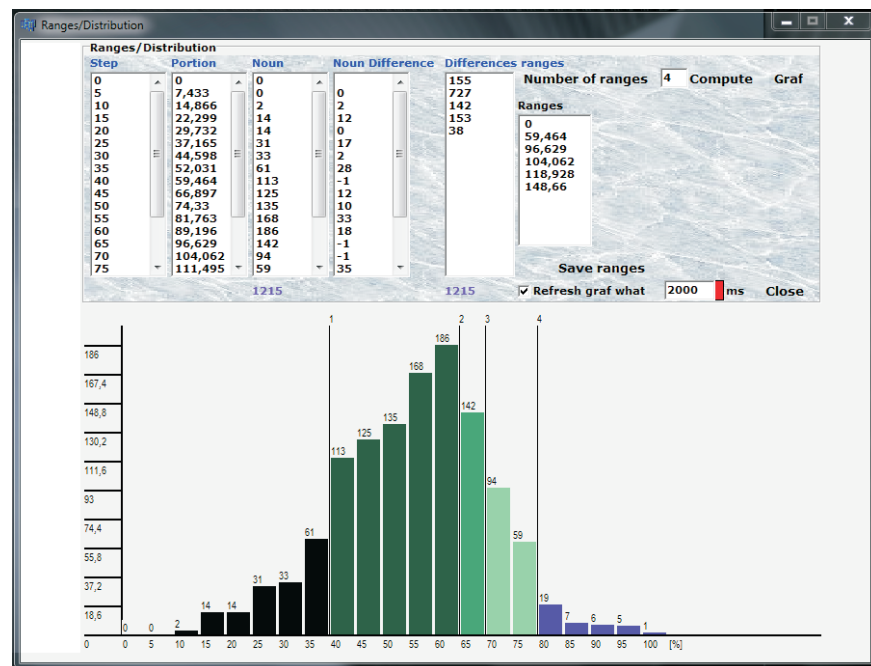


Figure 4. Distribution and ranges of values determined for the coefficient of the spliced strength of the joint retained (η_W) – an example.

above, a 10-grade quality scale was assumed.

For example, when considering a feature of an unknotted joint, from the point of view of the coefficient of the spliced strength of the joint retained – η_W (Figure 4), it can be stated that, as a result of dividing the database into 5 groups,

- 155 joints met the condition:
 $2 < \eta_W \leq 40\%$,
- 727 joints met the condition:
 $40 < \eta_W \leq 65\%$,
- 142 joints met the condition:
 $65 < \eta_W \leq 70\%$,
- 153 joints met the condition:
 $70 < \eta_W \leq 80\%$
- 38 joints met the condition:
 $80 < \eta_W \leq 100\%$.

Step 3. Selection of neural networks for the classification of joints

In order to classify the unknotted joints of yarn ends, an ADALINE (Adaptive Linear Element) model of a single neuron was proposed which formed neurons with output in the form of a linear function of activation, making it possible to obtain a neuron signal as real numbers [5, 8].

The model enabled to determine the weight of neuron joints – w_i , describing the properties of all the information concerning particular features of the spliced joints of yarn ends. In the case of applying another function of activation, one would obtain an output signal in the form of a bipolar function, as a binary code, which makes it impossible to compare the correlations of a particular sample and the original one. It would also exclude many important neurons from the general population, with the quality set a priori, making it impossible to classify the unknotted joints of yarn ends.

Step 4. Supervised learning of neural networks with the use of ALWA.

The Adaptive Linear Weighted Adder (ALWA) model was chosen for the process of supervised learning, in which the Delta rule was applied. The procedure of learning was carried out according to the scheme presented in Figure 5. A single neuron received input signals m , next a signal of number i was multiplied by the weight of number i until the value of i did not reach the value of m , set a priori.

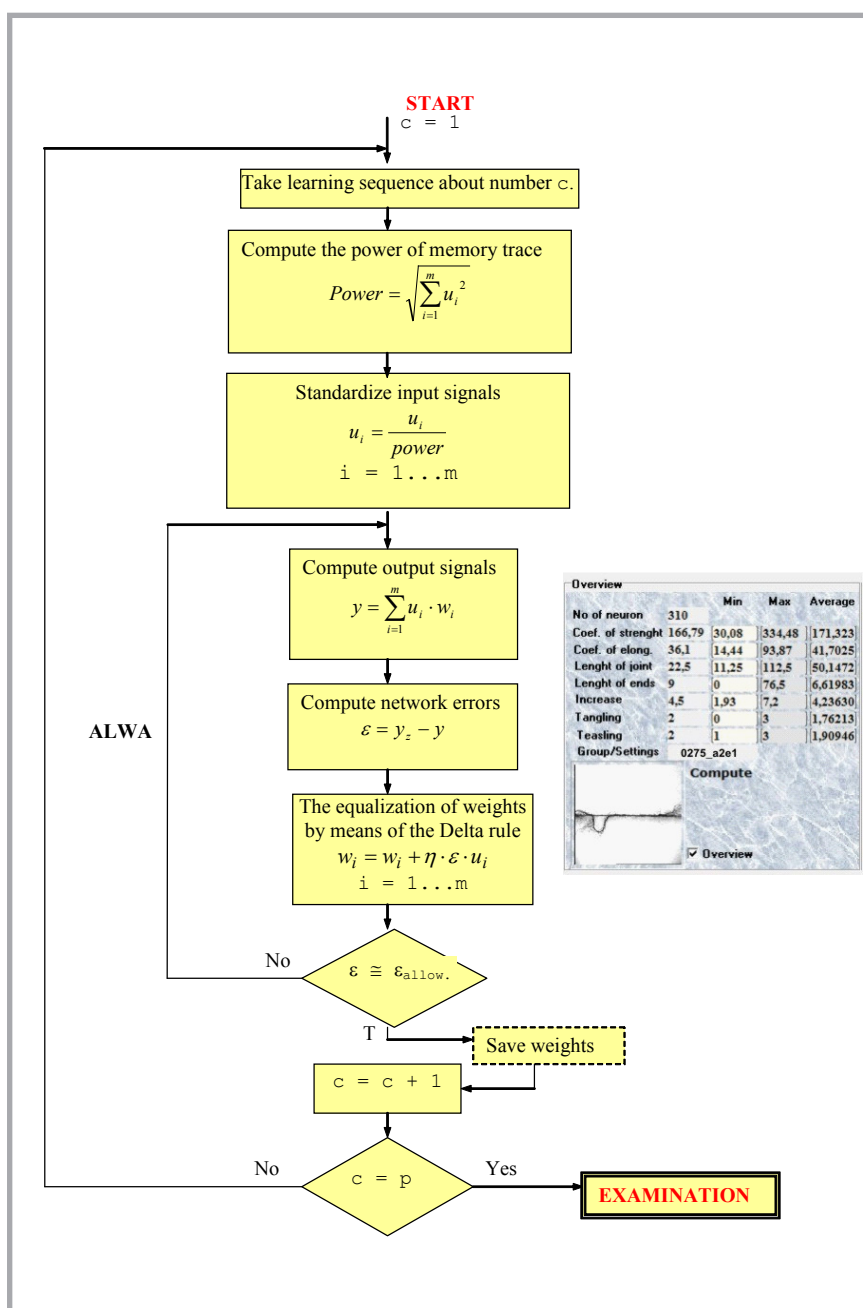


Figure 5. Procedure of the learning of a neural network using ALWA; y – value of neuron output signal, y_z – value of standard signal, ϵ – relative error of values generated by a neuron learnt with the Delta rule, ϵ_{dop} – acceptable error determining arbitrarily the accuracy of learning expressed by the decimal places, η – coefficient of learning, ϕ – function of activation, k – constant.

Such a task was realised with the use of an adder, which can be described as follows:

$$\sum_{i=1}^m u_i \cdot w_i \quad (5)$$

As a result, an output neuron y was obtained. An output signal of the ADALINE network is presented in the form of a linear function of activation - $y = f(\phi)$

That is:
$$y = \sum_{i=1}^m u_i \cdot w_i, \quad (6)$$

$$\epsilon_{dop} = y_z - y \quad (7)$$

The value of an error of neuron learning, which is the difference between the expected and actual output value, was determined using relation (5). In the case when real error was higher than an acceptable error – ϵ_{dop} , a correction of neuron weights was undertaken according to the Delta rule. If the values of the error evaluated were nearly the same as $-\epsilon_{dop}$, the neuron transmitted its activating signal to output y .

The procedure of the process of neural network learning - ADALINE using

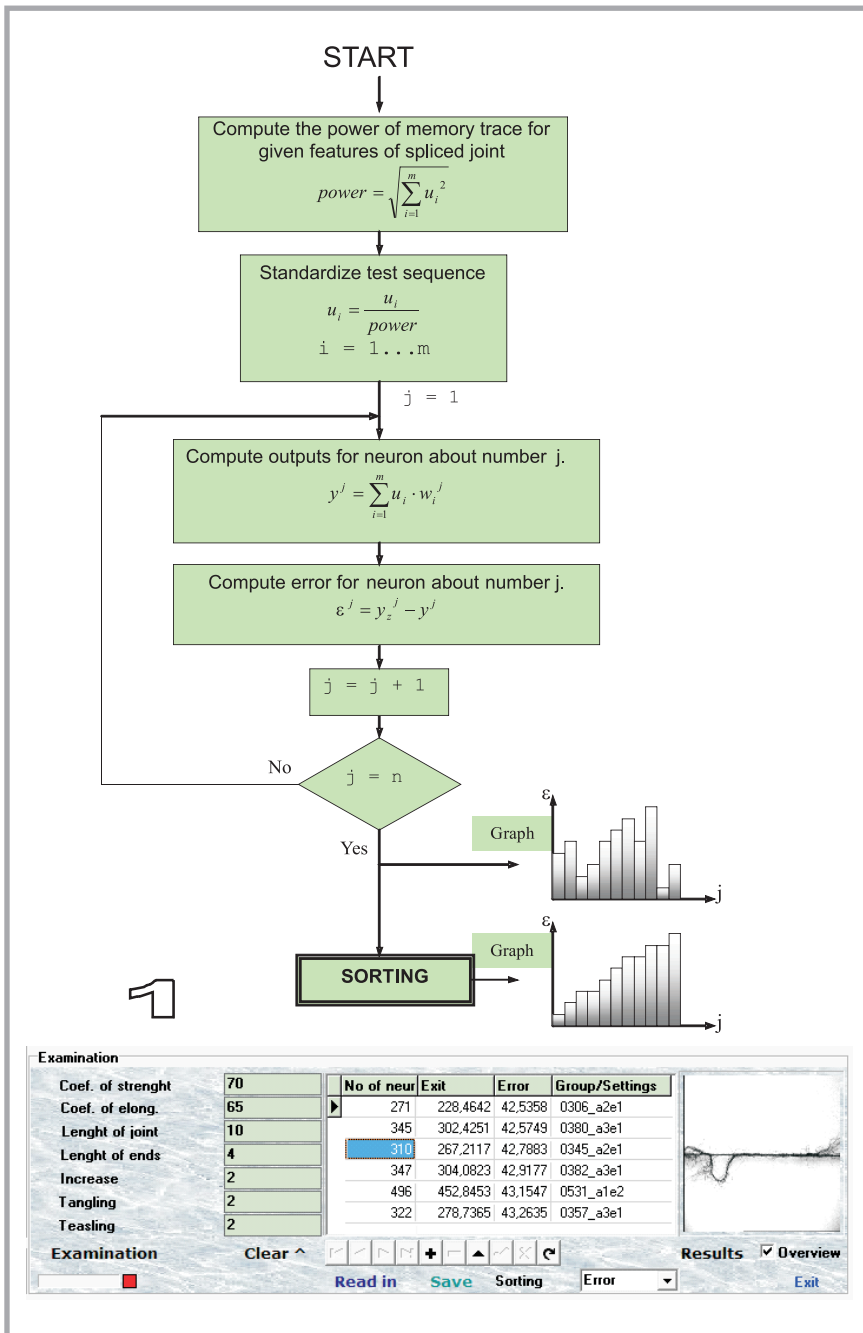


Figure 6. Procedure for the examination of a neural network using LWA and error sorting; 1) Process of the network examination of the author's C++ program. The interface presented enables to declare the given values of particular features of the spliced joint of yarn ends, on the basis of which the network is able to check them and sort the errors of learning in ascending order.

the Adaptive Linear Weighted Adder (ALWA) is presented in **Figure 5**.

Step 5. Examination of neural networks using LWA

The Linear Weighted Adder (LWA) model was applied to examine the validity of the networks. The examination process proceeded in the same way as the learning one. A single neuron received an m number of input signals, next the signal number i was multiplied by the weight number until i did not reach the value of m .

The task was realised using the adder described by **Equation 3**. As a result, the output neuron y was obtained. Likewise, for the ALWA model, the output signal of the ADALINE network was presented in the form of a linear function of activation (**Equation 5**). The value of an error of neuron learning, which is the difference between the expected and actual output value obtained, was determined by **Equation 5**. When the network was examined, its learning and correction of the weights of neurons was unnecessary.

The process of learning was conducted in Step 3 of the process, using the ALWA model. The procedure of the examination process of the ADALINE network using the Linear Weighted Adder (LWA) is presented in **Figure 6**.

Step 6. Sorting the errors of network learning in ascending order

In order to choose neurons characterised by the smallest errors, the neurons were sorted in ascending order. The smaller the error was, the more the particular neuron was similar to a standard sample of known features. A block scheme of the model describing the process of sorting neurons is presented in **Figure 6**.

Step 7. Assignment of importance (ranks 0-9) to particular features of the spliced joint of yarn ends

For each additive and non-additive feature of the joint, the quality was described by a 10-point scale and its importance defined. All the samples were put in a database as an amount of p . Every sample was submitted to the database in the form of a given structure, that is, the learning sequence c of number c , including the number of neurons n_n , and the vector of features $u_1 \div u_7$ and a group. On the basis of a given list of the quality of unknotted joints and neurons with the smallest errors selected, the sample was classified as one of 10 quality choices – **Figure 7** (see page 42).

Report of the results of classifying the unknotted joints of yarn ends and a summary

An example of a report of classifying the unknotted joints of yarn ends is presented in **Figure 8** (see page 43).

The analysis of the report indicates that the ADALINE artificial neural network with a linear function of activation used, found the joint with satisfactory accuracy, compared with the values of features of the joints given *a priori*, which were submitted to the program when the classification procedure started, and informed of the settings of the JOIN-TAIR 4941 splicing device used. The error of network learning, which did not exceed the value of acceptable error $\epsilon_{dop} = 0.001$, was decisive here. The result of this procedure, conducted according to the algorithm of neural classification (**Figure 1**), was a presentation of the results obtained in the form of histograms, a report containing results characterising the quality of the joint, an image of a classified sample, and values of the settings of the splicing device.

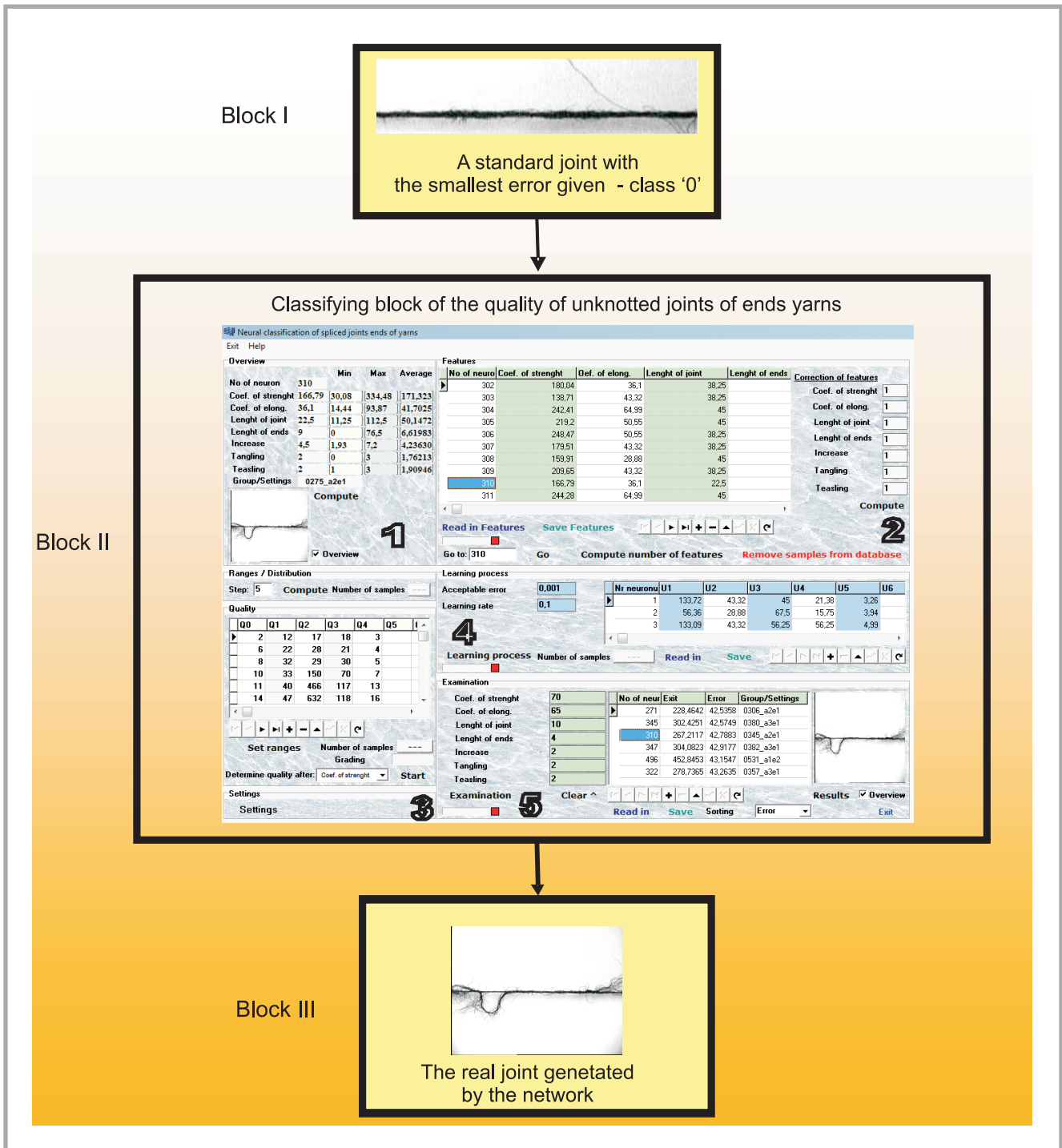


Figure 7. Scheme of classifying the unknotted joints of yarn ends into particular lists of quality; Block I – a standard joint with the smallest error given – class “0”. Block II – classifying block of unknotted joints of yarn ends. Block III – the real joint generated by the network. 1). Overview – declaration of given values of particular features of the joints of yarn ends. 2). Interface, which enables to generate neurons, edits any values of the database, adds or deletes neurons and submits features to the database declared. After submitting and counting all the features, they can be corrected by enhancing or weakening the weights of the joint. 3). Classification submenu of the joints and the procedure of scheduling its quality choices. 4). Interface of learning of the network, which enables to display the number of samples subjected to the learning process. 5). Interface of examination of the network, which enables to calculate the errors of each neuron with the features given, as well as classify, read in and submit the results obtained.

Conclusions

On the basis of the analysis conducted, it can be stated that:

1. ADALINE, an artificial neural network with a linear function of activation, designed for the recognition and

classification of unknotted joints of yarn ends made of worsted woollen yarns, is characterised by simplicity as recognising the joint and its classification is based only on creating a database and determining the features of the object evaluated. All the other

processes, such as learning, examining, sorting, classification and making a report are carried out automatically.

2. The network recognises perfectly the unknotted joints of yarn ends collected in a database of joints and also evaluates their quality effectively.

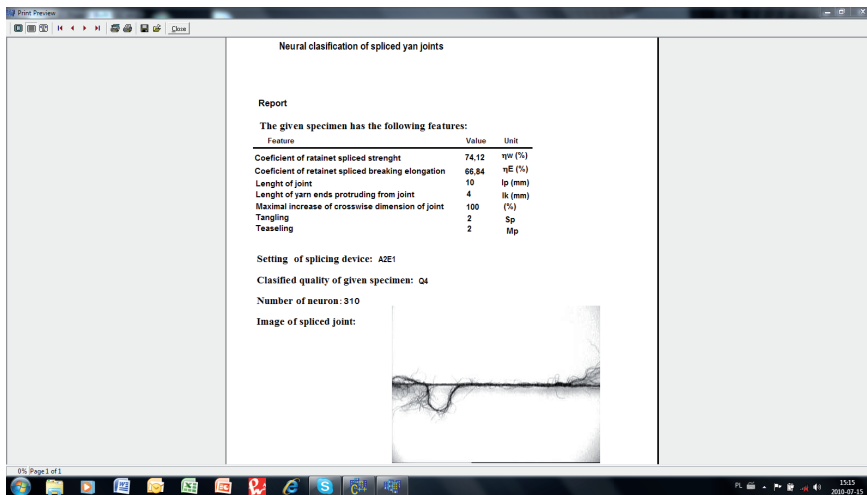


Figure 8. An example of a report of the results of classifying the unknotted joints of yarn ends. The report includes the results of sorting and examining the network, giving the values of particular features of joints and quality choices thereof, the number of neurons, an image of a joint, as well as the settings of the JOINTAIR 4941 splicing device, made by MESDAN.

- The application of an artificial neural network of the ADALINE type as a prediction tool for the classification of joints enables to simplify the measuring process.
- With respect to the method of sample classification, it can be noted that the quality of spliced joints of yarn ends changes significantly. The evaluation of quality depends on the criteria for classification of the non-additive features of joints determined, such as tangling and teaseling, as well as the preferences of particular features.
- An artificial neural network, after some modifications concerning the

definition of the features, can be applied for evaluation of the quality of other features of raw materials or textile products. For example, it can be used for the impurity evaluation of cotton, as well as the quality evaluation of cotton or different errors occurring in flat textile products.

- Thanks to the observation of the correlation between the technological working parameters of the splicing device and characteristics of spliced joints of yarn ends, it is possible to establish its optimal working conditions.

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