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Prediction of Properties of Unknotted Spliced Ends of Yarns Using Multiple Regression and Artificial Neural Networks. Part I: Identification of Spliced Joints of Combed Wool Yarn by Artificial Neural Networks and Multiple Regression

Abstract
Applying the software environment Statistica for neural networks allowed the use of artificial neural networks and regression analysis to predict the physical properties of unknotted joints of yarn ends. The database entered into the network was built on the basis of determining characteristic geometric dimensions and the strength properties of joints, as well as assessing non-additive features, represented by teaseling and tangling. Networks of the multilayer perceptron type (MLP) and generalized regression neural networks (GRNN) were used. In order to compare the results, multiple regression was also applied.

Key words: *combed wool yarn, pneumatically spliced joints, additive quantities, non-additive features, artificial neural network, multilayer perceptron, generalized neural network, back propagation algorithm.*

Introduction

Artificial neural networks (ANN) are a computer tool that makes possible the design of non-linear models to solve complicated and difficult to identify classificatory and regression tasks [1]. ANN exemplify a group of numeric algorithms used for the approximation of the function, grouping, and then classifying of data, as well as for solving for each the problems of optimization. The usage in the analysis of complicated data of ANN is especially profitable since it leads to designs of models based on properties of the actual data, rather than hypotheses accepted arbitrarily [1]. ANN are especially useful for searching for more complex relationships between the input and the output. Such forms are more difficult to express by means of the statistical terms usually used for such cases, e.g. "correlation" [1]. The main advantage of ANN is the fact that they are equipped with non-linear algorithms of regression, and possess the ability to model multidimensional systems with maximum flexibility under the consideration to learn them.

The main advantage of artificial neural networks over classic algorithmic methods lies in the fact that full knowledge of the issue of the model is necessary in the classic method (which, thanks to industry technological conditioning, very often isn't possible to realize), permitting the formulation of "fixed" rules of inferring, while the artificial neural network possesses the ability "to programme itself" on the basis of examples fed to the set-up. The wide range of possibility of the ANN [2-3] also made them find an application in the textile industry, beginning from fibres, but ending in final goods. Numerous examples of applications of artificial intelligence in the textile industry were comprehensively described in article [4]. ANN are also able to be applied for solving problems linked to the improvement in the quality of the spinning process and produced yarns.

Mathematical tools devoted to the optimization of the process of unknotted joining of yarn ends on winding machines

Issues published so far have referred to the presentation and the explanation of physical models of threads primarily in the splicing chamber, as well as to the principles of working of splicing devices. Such research was led by Bissman inter alia [5], Gebald [6], Kaushik, Sharma, Hari [7-10], as well as Drobina, Machnio and Włochowicz [11], and Drobina, Włochowicz, Machnio and Józkowicz [30]. Frontczak-Wasiak and Snycerski [12] first made an attempt to specify the criteria of quality estimation for unknotted joints of ends of threads, partitioning them into strength properties, geometric dimensions and non-measurable features in general. Only physical properties were evaluated in the led research, as well as the appearance of the obtained joints, without their graphical presentation in the form of photos, images and the like. Drobina and Machnio [13-14] offered

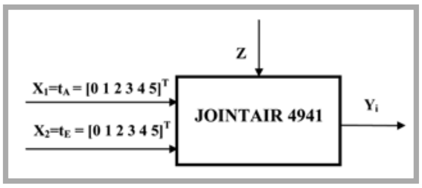

***Figure 1.** Plan of research of physical properties, geometric dimensions and non-measurable features of spliced joints of yarn ends, X_1 – first input variable, X_2 – second input variable, t_A – time of splicing cycle, t_E – time of untwisting yarn ends for splicing, z – non-measurable disturbances of winding and splicing processes, Y_i – additive and non-additive quantities of unknotted spliced joints of yarn ends (position t_A = 0 and t_E = 0 – the shortest time – 100 ms; position t_A = 5 and t_E = 5 – the longest time – 600 ms).*

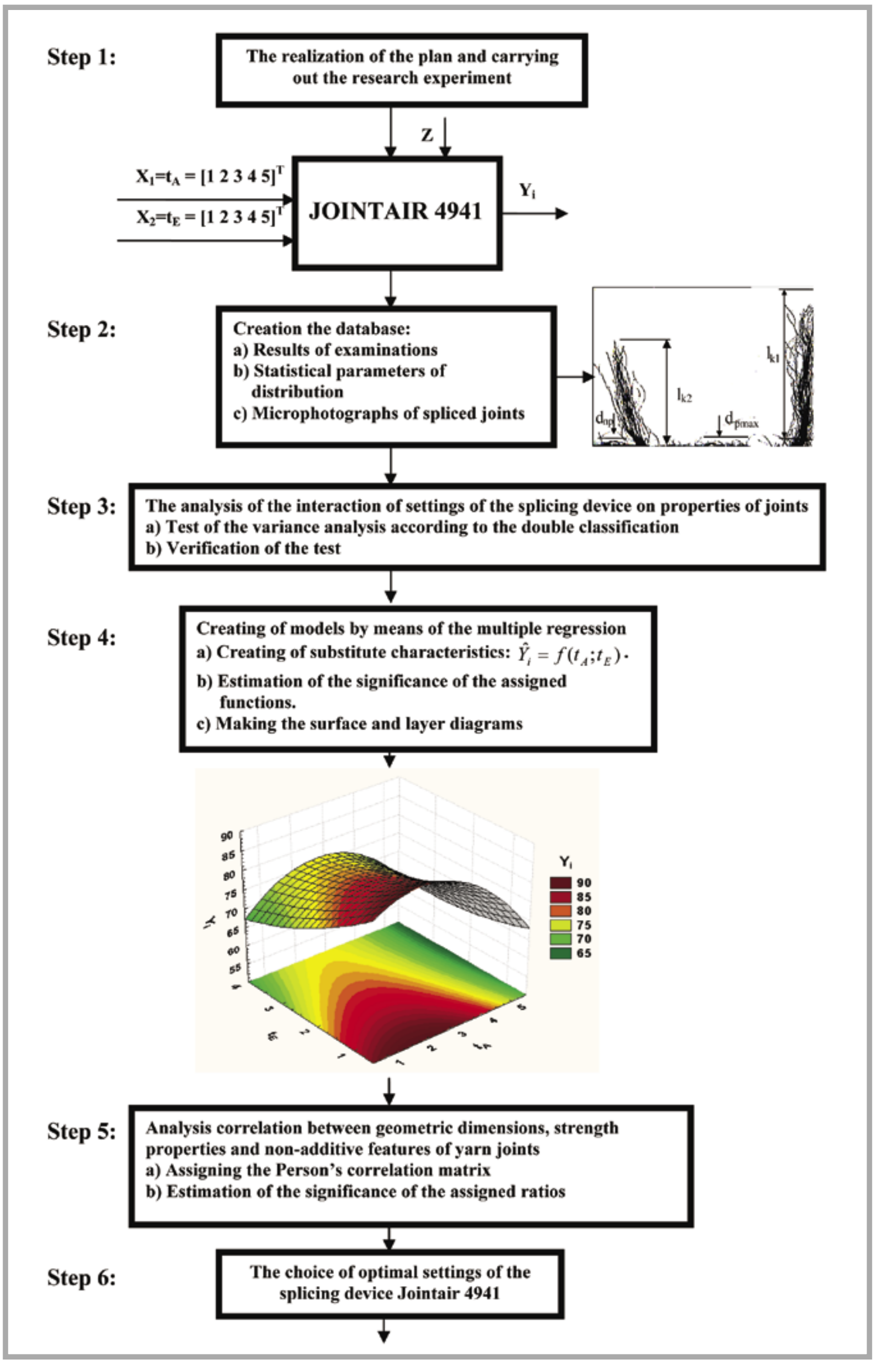

Figure 2. *Procedure of research referring to the modelling of the process of unknotted splicing joints of yarn ends using multiple regression.*

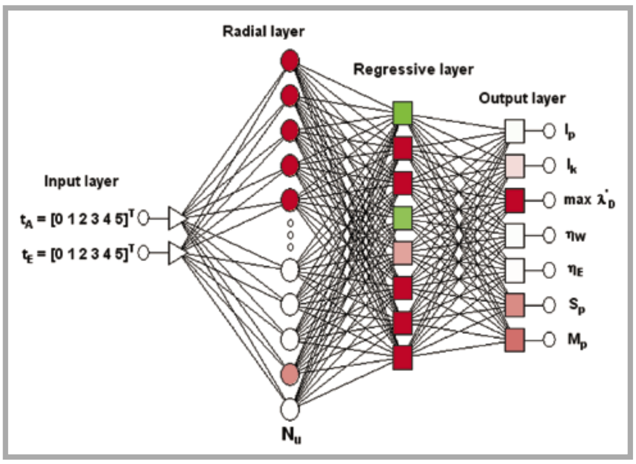

Figure 3. *Example of global GRNN network 2–N_u–8–7, where Nu = N/2 – number of neurons in the radial layer and N – number of experiments.*

similar criteria, during research into unknotted joints of ends of threads manufactured from worsted woollen yarns, joined with the technique of pneumatic splicing, and first they presented patterns of these joints.

The first publications presenting research connected with the estimation of the relationship between the properties and the appearance of the joints, but with working parameters of splicing devices investigated with regard to their optimization, are works performed by such authors as Cheng and Lam [15-16], Lewandowski and Drobina [17] and Drobina and Machnio [18]. Cheng and Lam [15-16] used the mathematical tool in the form of linear regression and orthogonal regression. Next, Lewandowski and Drobina [17], as well as Drobina and Machnio [18], applied the mathematical tool in the form of multiple regression, receded with the analysis of variance test according to the double classification. The next research was led by Issa, Grütz [19] and Hasen and Sakli [20].

Cheng and Lam [21], as well as Lewandowski and Stańczyk [22-23] made attempts to enter ANN into solving issues connected with predicting the physical properties of unknotted spliced joints of yarn ends, as well as with their identification and classification.

Mathematical modelling of the physical properties of spliced joints of yarn ends using multiple regressions

Creating the Basis of Unknotted Joints of Yarn Ends

The integer experiment was carried out in order to verify the accuracy of the selection of the neural model and compare it with the model based on the multiple regression 6 × 6 – ***Figure 1.*** The modelled input variables (explaining variables) were time of untwisting yarn ends for splicing – t_E and time of splicing cycle – t_A, whereas the output variables (explained variables) – Y_i were properties of unknotted joints of yarn ends characterized by additive and non-additive quantities. The characteristics of the splicing device Jointair 4941 of the MESDAN firm, together with determining its settings, were described in articles by such authors as Drobina and Machnio [13-14] as well as Lewandowski and Drobina [17].

It is possible to apply mathematical models verified on the selected level probability. It is necessary to remember the careful criteria for the selection of input variables. While leading the experiment, it is necessary to realize the consequences of changing the settings of the working parameters of the splicing device and changing the properties of the processed assortment and to connect with them non-measurable disturbances. An extremely difficult issue is designing the plan of the experiment to be carried out in industry conditions in such a way that the characteristics of the technological operation are obtained like most information. The total experiment imposes "stiff" conditions of selection of the grid of input variables (explaining variables) in the case of the application of multiple regression. The lack of a chance to carry out an active experiment for at least one point of the active experimental plan causes a deformity image of the plot surface of the response for the given actuating signals, as well as narrowing of the experimental plan. This narrowing automatically causes the reduction of the penetration space of events and increases the probability of the loss of hypothetically optimal settings [31]. In the case of the construction of the model based on artificial neural networks, such a problem does not occur, because the missing values are replaced with average values (or with other statistics) calculated on the basis of accessible values in the learning sequence [32]. The mathematical modelling of the physical properties of spliced joints of yarn ends using neural regression will be presented later.

However, it is necessary to remember that, among the leading methodologies of research, the mathematical tool in the form of multiple regressions is currently the most widespread and recommended, in spite of the limitations enumerated above.

For the estimation of consequences of the interaction settings with the working parameters of the splicing device on the properties of the unknotted spliced joints of yarn ends in the first order, the test of the variance analysis according to the double classification was applied [34], and then regressive analysis along with assigning the regression functions approximated by means of linear-square polynomials.

The compatibility between the output of the object and the output of the model was judged on the basis of such values as [32], [35]:

$$\hat{Y}_i = B_0 + B_1 \cdot t_A + B_2 \cdot t_E + B_{11} \cdot t_A^2 + B_{22} \cdot t_E^2 + B_{12} \cdot t_A \cdot t_E \qquad (1)$$

- R – ratio of the multiple correlation,
- F-Snedecor's statistics – $F_{calc.} = F_{\alpha=0,05}$ (K; $N-K-1$) and $F_{crit.}$,
- partial t-Student's statistics of – $t_{\alpha=0,05}$ ($N-K-1$) assigned to the estimation of significance for each term of the regression functions,
- B_0, B_1, B_2, B_{11}, B_{22} – coefficients of the regression function.

The stepping procedure of the research referring to the modelling of the process of unknotted splicing joints of yarn ends using multiple regression is shown in ***Figure 2***.

Plan of technological identification of the pneumatic splicing process of ends of yarns necessary for the verification of the architecture of SSN

Construction of the Artificial Neural Network Realizing Regressive Operations Mathematical Model of a Neuron

The artificial neuron is the special converter of signals, operating according to determined principles [1], [2]. The model of the artificial neuron includes the block of the summation – Σ and block of the activation – F. The algebraic summation of weighed input signals is realized in the block of the summation and the output signal y is generated, the potential of which it is possible to calculate from formula [1]:

$$\varphi = \sum_{i=1}^{m} w_i \cdot u_i = w^T u\,, \qquad (2)$$

where:
u – vector of input signals, in this case, the working parameters of the splicing device, w – vector of ratios of weight of connections, $\mathbf{w}^\mathbf{T}$ – operator of transform of the vector or the matrix, in addition: $\mathbf{w}^\mathbf{T} = [w_1, w_2,..., w_N]^T$, m – number of inputs of the neuron, y – vector of output signals, properties of spliced joints of yarn ends.

The **S** signal is processed by the block of activation **F**, which is able to be characterized with various functions. During the construction of ANN, linear $f(x) = x$ and logistic $f(x) = \dfrac{1}{1+e^{-x}}$ functions were applied to the prediction properties of spliced joints of yarn ends.

Creating the Optimal Architecture of the Artificial Neural Network

When modelling functional relationships by way of ANN, the structure of the network and the proper selection of the learning data are of the greatest importance. Applying the global network, about the extended architecture, designing a model for the physical properties of unknotted spliced joints of yarn ends is a very complex issue. The example of the global GRNN 2–N/2–8–7 network is shown in ***Figure 3***.

In the view represented by Jackowska-Strumiłło, Jackowski, Cyniak and Czekalski [24], in the majority of cases of ANN usage [24], the values of the single output variable are sought. When the need for the calculation of a few output variables occurs at the same time, the application of the separate network is the optimum solution, even when actuating signals are repeated several times [24]. The literature reports [25] show that the package of separate networks often operates better from the single, monolithic network.

Taking into account the above-mentioned and taking other conditioning into consideration, the package of artificial neural networks was designed with the architecture 2–N_u–1, i.e. two neurons in the input laser, N_u neurons in the hidden layer and one neuron in the output layer, each of every time other, depending on the predicted parameter of unknotted joining of the spliced yarn ends.

Selection of the Kind of Artificial Neural Network

Many types and kinds of neural network exist, differing in the structure and principles of the operation. It is possible to divide artificial neural networks with regard to the flow of information for feed-forward networks, and recursively with the feedback. In turn, taking into account the number of ANN layers, they are divided into one-layer and multilayer [1, 4-26]. They stated on the basis of the carried out research and the analysis of the review of literature [1, 4-26], that MLP and GRNN networks are most useful for the realization of regressive tasks and for the prediction of the properties of unknotted spliced joints of yarn ends.

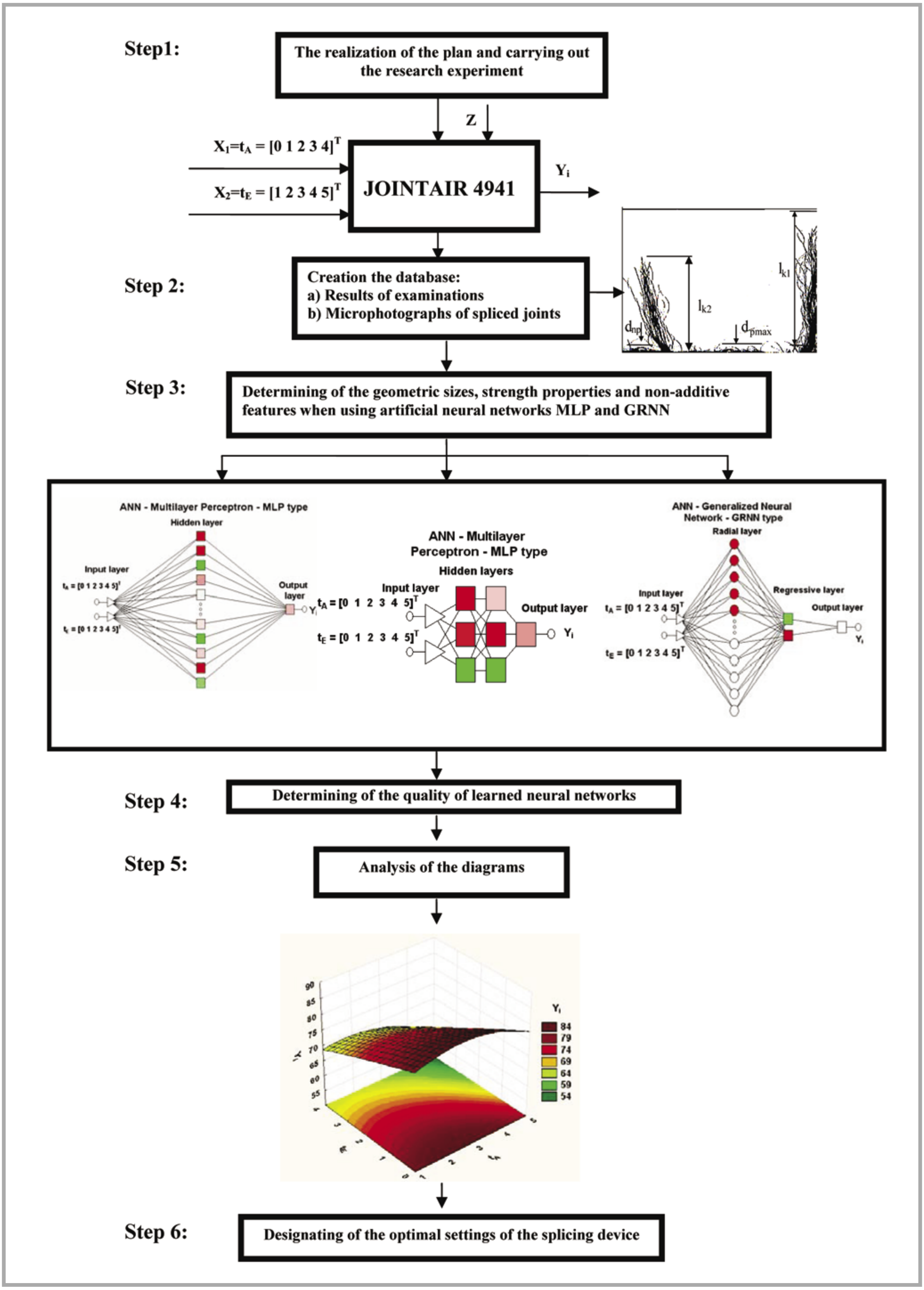

Figure 4. Procedure of research referring to the modelling of the process of unknotted splicing joints of yarn ends using neural regression.

Table 1. Plan of research using artificial neural networks of the MLP type

Item number	Analysed kind or parameter of network	Parameters of ANN											
1.	Form of the activation function	Linear						Logistic					
2.	Number of hidden layers	1			2			1			2		
3.	Number of neurons in the hidden layer	1	2	3	1	2	3	1	2	3	1	2	3

Table 2. Physical properties of fibres and physical properties of yarn assigned to executing spliced joints [36].

Analysed parameters	Unit	Value
Woollen tops		
Average 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
Yarn		
Linear mass	tex	15
Direction and number of twist T	rev/m	Z770
Breaking force F_r	cN	75.48
Breaking tenacity W_t	cN/tex	5.03
Coefficient of breaking force $V(F_r)$	%	17.62
Relative breaking elongation ε	%	7.48
Coefficient of variation of linear mass – $CV_{8\ mm}$	%	20.58
Number of thin places	szt./1 km	65.2
Number of thick places	szt./1 km	217.2
Number of neps	szt./1 km	512.8

Selection of the Algorithm of Learning an Artificial Neural Network

There are in existence six available learning algorithms of ANN MLP in the STATISTICA for NEURAL NETWORKS program, such as the Back Propagation of the Error Algorithm, Algorithm of Conjunctive Gradients, Levenberg and Marquardt Algorithm, Delta-bar-Delta Algorithm, Quick Propagation Algorithm and Quasi Newton Algorithm [25].

The process of learning of the network in the presented research was realized by means of so-called supervised learning, by way of the Back Propagation Algorithm of the Error and the Algorithm of Conjunctive Gradients. Mathematical modelling of the Back Propagation Algorithm of the Error can be found in works by such authors as Zieliński [2], Korbicz, Obuchowicz and Uciński [3], Rutkowska, Piliński and Rutkowski [27], as well as Ossowski [28].

Elaboration of the Plan of the Experiment that enables the creation of ANN

As was already previously mentioned, the computer program Statistica for neural networks was used to learn the artificial neural networks. To solve the regressive as well as the classificatory problems, the mentioned program was equipped with two types of leading of the analysis:

- designer of the user of the network,
- automatic designer network.

When using the designer of the user of the network and applying the MLP network, the following plan of research presented in ***Table 1*** was proposed. For every kind of network, the linear function of the activation and the logistic one was applied.

The following were accepted as constant parameters: learning rate: 0.01, inertia: 0.3, number of learning epochs: 100 in the first phase, learned by means of the Back Propagation Algorithm of the Error, and 500 in the second phase, learned by means of the Algorithm of Coupled Gradients.

The characterized MLP network itself consisted of two input nodes in the input layer – t_A i t_E; one or two hidden layers; one, two or three neurons in hidden layers and one neuron in the output layer for every examined physical parameter of spliced joints of yarn ends.

For the design of GRNN networks were applied:

- random assigning of centres of base functions,
- cardinality of subsets: learning – equal to ¼ of the total cardinality of the set of data, validation – equal to ¼ of the total set of data, testing – equal to 1 of the total set of data,
- the number of hidden neurons equal to the number of learning cases,
- smoothing ratio equal to 0.2.

The validation set served to monitor the network learning process; however, the testing set did not participate directly in this learning process. It was used for verifying the obtained results of the research.

Analysis of the Effectiveness of Mapping the Artificial Neural Network

In accordance with the assumed research programme, the effectiveness of mapping ANN was assessed with regard to: the interaction kind of the network (MLP or GRNN), the kind of activation function (linear or logistic), the number of hidden layers (one or two) and the number of neurons in the hidden layer.

To reflect the estimation effectiveness of every ANN, the following indicators were accepted:

- quality: learning, validation and testing,
- error: learning, validation and testing,
- mean error, deviation of error, mean absolute error,
- quotient of deviations,
- Pearson's correlation.

From every programmed network, surface plots of the response and their projections for the surface were also made in the form of layer plots. The stepping procedure of the research referring to modelling the process of unknotted splicing joints of yarn ends using neural regression is shown in ***Figure 4***.

Subject of investigations and methodology of measurements

The subject of technological identification was the pneumatic splicing process of ends of yarns realized on the splicing device Jointair 4941 of the MESDAN company integrated with the automatic winding machine ESPERO of the SAVIO firm. The subjects of the research were unknotted joints of ends of yarn produced from the worsted weaving woollen yarn – 15 tex, Z770.

The process of spinning was realized on the ring spinning machine FIOMAX 2000 of the SŰESSEN firm. The physical properties of the woollen tops, as well as the physical parameters of the yarn, are set together in ***Table 2.***

Methodology of Measurements

The methodology for determining the additive quantities represented by the geometric dimensions of the unknotted joints of yarn ends were derived from Drobina's and Machnio's article [18], [29]. The strength properties of unknotted joints of yarn ends were assigned in accordance with the standard PN-EN ISO 2062:1997 and were derived from Lewandowski and Drobina's article [17]. Non-additive features were assessed in accordance with the methodology characterized by works by Drobina and Machnio [14] as well as Lewandowski, Drobina and Kasztelnik [31]. During the creation of architectures of ANN, parameters were assigned for each property of the spliced joints of yarn ends (interpreted variables). With regard to the extensive base, these values were taken down from editing in available appendices Fibers periodicals & Textiles in Eastern Europe.

Research question

Taking into consideration the above-mentioned reflections, the following hypothesis H_0 could be formulated:

"Which of the proposed models (artificial neural network or multiple regression) assure better prediction abilities, taking into account the technological identification of the process of the unknotted joining of yarn ends?"

Conclusions

1. The technological identification of the process of the unknotted joining of spliced ends of yarns with the proposed models will make it possible to determine the character of the phenomena discussed, and even the choice of optimal settings of the splicing device.

2. The verification of the models proposed and the research question mentioned above will be the subject of the next article entitled: "Prediction of Properties of Unknotted Spliced Ends of Yarns Using Multiple Regression and Artificial Neural Networks, Part II: Verification of Regression Models".

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