The predictive development of the electroconductive textile using artificial neural network

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Abstract. This paper presents several aspects concerning the predictive development of the electroconductive textiles based on the artificial neural network. The electroconductive textiles have been obtained using thin film coating with metal micro/nanoparticles and printing. For these textiles, we have made a mathematical model and we optimized dependent parameters, such as pH, dispersion conductivity, mass, thickness, air permeability, and surface resistance, by neural networks based on optimization algorithm Levenberg-Marquardt back propagation. The methodology consists in developing three feed-forward neural networks that are capable of estimating the surface conductivity of the textile materials, based on six parameters obtained in the laboratory. Moreover, this work is significant in the development of surfaces with conductivity directed to obtain the antistatic, electroconductive textiles or insulators, starting from input matrix values.

1. Introduction
The concerns in the use of the artificial neural network (ANN) for predictions in the field of textile was demonstrated through numerous researches such as prediction of the fabric behavior as output by yarn properties and machine settings as inputs [1] or in fiber to yarn prediction [2]. Neuronal networks can be used for the prediction of the parameters of the textile materials based on advanced micro/nanoparticle submitted through various methods of finishing (foulard, thin film deposition, and direct printing).

In scientific literature, the neurons are defined as units of account with a k-output and input (i1, ..., ik). The output is neuronal terminal which provides the result of the calculations which were carried out. The inputs are the terminals through which the neurons collect the information from various sources to be processed. Each entry, ith, is associated with a coefficient of transfer, weighted synaptic (wih) [3, 4]. Each neuron has a function of the response to the excitation, f (depending on neuronal, depending on the Exit or the activation function) [5, 6, 7].

The mathematical model for a process can be achieved by an analytical or experimental method using dependent and independent variables. The identification of the parameters for the experimental method involves the construction of the mathematical model based on the processing of functional variables (inputs, outputs) associated with the process. The model identified in the process is determined from an experiment conducted in the laboratory (offline) based on representative data sets acquired during the experiment, and does not change because it is assumed that the parameters of the process remain constants during the experiment. Identification of the parametric modeling, experimental, involves the construction of the mathematical model in the field of discreet time, based
on the operational processing variables (input, output) associated with the process.

In general, the predictive modeling and advanced solutions for intelligent data analysis require powerful software applications, specially designed for the rolling of complex algorithms on large data sets. For modeling and prediction of the parameters in the complex experiments, we used multiple CPUs such as grid type Systems Network or Cluster Computing. For the prediction, we used neuronal networks. This paper presents the prediction of the parameters for electroconductive textiles, based on input/output variables and the ANN method [3].

2. Material and Methods
To achieve this objective was designed three neuronal networks, feed-forward (figure 1), to estimate the surface conductivity of the textile material based on six parameters obtained in the laboratory (earth, thickness, conductivity, pH, air permeability, surface resistance). Functional units within the neural network consisted in:

- Units of input (input) represented the values of the matrix Inputconducitvetex 6x9, which defines the six attributes for nine tests.
- The hidden units (Hidden) are identified by the number of neurons (10, 30 and 40 respectively of neurons).
- The output (output) represented by the array Outputconducitvetex values, which defines the conductivity attribute the surface for the nine tests.

![Figure 1. Feedforward neural network.](image)

The input data used in the matrix inputconducitvetex (Table 1) correspond to the values obtained by laboratory tests.

| pH | Conductivity [µS] | Thickness [mm] | Air Permeability [l/m²/sec] | Mass [g/m²] | Surface Resistance Rs[Ω] |
|----|------------------|----------------|----------------------------|------------|------------------------|
| 5.45 | 211              | 1.041          | 16.24                      | 619        | 1.3×10⁹               |
| 5.96 | 155              | 1.148          | 8.21                       | 565        | 1.29×10¹⁰            |
| 4.86 | 163              | 1.112          | 8.73                       | 592        | 1.2×10⁹              |
| 7.15 | 268              | 0.821          | 16.28                      | 596.5      | 1.1×10⁹              |
| 7.53 | 191              | 1.041          | 23.78                      | 494        | 1.2×10⁹              |
| 5.41 | 129              | 1.13           | 16.36                      | 604        | 1.4×10⁹              |
| 6.25 | 90               | 1.07           | 13.62                      | 509        | 1.8×10¹⁰            |
| 6.7  | 101              | 1.079          | 8.662                      | 592        | 1.4×10¹⁰            |
| 5.76 | 164              | 1.165          | 21.48                      | 781        | 1.5×10¹⁰            |

In the framework of the neuronal network ten layers hidden neurons (figure 2), 30 neurons (figure 3) and 40 of neurons (figure 4) have been used for the approximation of functions between the conductivity of the surface and the six input parameters Inputconducitvetex matrix. For the optimization Levenberg-Marquardt algorithm that uses an approximation of the Hessian matrix (H) has been used as followed:

\[
H = J^T J
\]
Where:
- $J$ is a Jacobian matrix which contains the error function derivatives about the weights ($w$) and bias ($b$)
- $J^T$ is transposed Jacobian matrix
- $e$ is the vector of the errors.

The Levenberg-Marquardt algorithm uses the following rule for updating the parameters:

$$ x_{k+1} = x_k - [J^T J + \mu I]^{-1} J^T e $$

(2)

Figure 2. Neural network based on 10 neurons

Figure 3. Neural network based on 30 neurons

Figure 4. Neural network based on 40 neurons

For the networks based on 10, 30 and 40 neurons, the regression $R$ (figures 5, 6 and 7), which measures the correlation between the outputs and objectives, and histogram errors (figure 8) have been represented. From graphs associated with the validation (figure 5 and figure 6) the value of the regression $R = 0.95941$ and $R=1$ shows a good match between outputs and the objectives. From the regression graph (figure 7), it can be observed that the value of the regression to the test, training, and validation is 0.84013, which indicates a good match between inputs, outputs, and objectives.

Figure 5. Graphical representation of the regression – neural network based on 10 neurons
3. Results and discussion
Using the experimental data obtained, a mathematical model for surface conductivity of the fabric has been developed using the parameters (surface resistance, dispersion conductivity and pH) leading to the obtaining of the antistatic, conductive or insulator materials. The mathematical model obtained for the expression of the surface conductivity based on the dispersion conductivity (x) and pH (y) is given by the math expression (3):

$$z = f(x,y) \iff z = a + bx + cy + dx^2 + ey^2 + fxy$$

Where:
$$a = 0.00000001582; b = 0.0000000000321; c = -0.000000004078; d = 0.0000000000006406; e = 0.00000000002843.$$

In order to analyse the outliers values, the coefficient of determination (correlation between multiple square values of response and the response values predicted R –square), the value of R-square adjusted (Adjusted R-square = 0.386), the amount of the range due to errors (SSE) and the
square root of the root mean square error (RMSE = 2.767e-10) have been used.

\[ \text{R-square} = \frac{SSR}{SST} \quad \iff \quad \text{R-square} = 0.7698 \]  

(4)

\[ \text{SSE} = \sum_{i=1}^{n} w_i (y_i - \hat{y}_i)^2 \iff \text{SSE} = 2.296e - 19 \]  

(5)

Where:

- SSR is the sum of squared residuals (6);
- SST is the sum of squares due to regression (7);

\[ SSR = \sum_{i=1}^{n} w_i (\hat{y}_i - \bar{y})^2 \]  

(6)

\[ SST = \sum_{i=1}^{n} w_i (y_i - \bar{y})^2 \]  

(7)

In figures 9 and 10, the surface conductivity according to the pH and conductivity of the dispersion based on metal micro/nanoparticles (C) using the mathematical model (3) are represented in 3D and 2D, respectively.

![Figure 9. 3D representation- surface conductivity according to the dispersion conductivity and pH based on the mathematical model.](image)

By analyzing the covariation between two variables C and pH (8) containing the numerical values for the parametric model, it can be concluded that between pH and C there is a direct dependence.

\[ \text{cov}(C, pH) = 1.0e + 03 \times \begin{bmatrix} 3.0630 & 0.0119 \\ 0.0119 & 0.0008 \end{bmatrix} \]  

(8)
4. Conclusion
In conclusion, the increase in the number of neurons in the neuronal networks leads to the values of the appropriate regression that indicates a good match of the mathematical model. By variation of micro/nanoparticles quantity, conductivity obtained for dispersions at pH >7 is 30% higher than the one obtained for dispersions with acid pH (<7). The values of the regression R obtained, close to 1 for testing, learning (training) and validation in neuronal networks show a good match with the values predicted for the conductivity of the surface using the mathematical model and the experimentally obtained values. The use of the neuronal networks based on the optimization algorithms leads to the obtaining of the predictive values for the surface conductivity and the choice of the optimum set of experimental parameters that lead to the obtaining of textile surface with the electrical resistance values appropriate for antistatic and conductive properties.

Acknowledgments
The research presented in this paper was prepared in the INCDTP laboratories. This scientific paper is funded by the Ministry of Research and Innovation within National Project "Optimizing the performance of the functional textile by advanced technologies", Contract PN 18 23 01 05 and Program 1 - Development of the national RD system, Subprogram 1.2 - Institutional Performance - RDI excellence funding projects, Contract no. 6PFE/2018.

References
[1] Yang S, Gordon S 2018 Fiber-to-yarn predictions Engineering of High-Performance Textiles ed Woodhead Publishing pp 81-106
[2] Neha C, Nirmal Y and Nisha A 2018 Applications of Artificial Neural Network in Textiles International Journal of Current Microbiology and Applied Sciences 7 (4) pp 3134- 3143
[3] Cochocki A and Unbehauen R 1993 Neural networks for optimization and signal processing ed John Wiley & Sons
[4] DeGroff D and Neelakanta P S 2018 Neural network modeling: Statistical mechanics and cybernetic perspectives ed CRC Press
[5] Krogh A and Vedelsby J 1995 Neural network ensembles, cross-validation, and active learning Advances in neural information processing systems pp 231-238
[6] Zhang Z 2018 Artificial neural network Multivariate Time Series Analysis in Climate and Environmental Research ed Springer Cham pp 1-35
[7] DeGroff D and Neelakanta P S 2018 Neural network modeling: Statistical mechanics and cybernetic perspectives ed CRC Press