MODELLING OF UNIT CONTACT SURFACE OF BEAN SEEDS USING ARTIFICIAL NEURAL NETWORKS

Marek Wrobel, Jaroslaw Fraczek, Slawomir Francik, Zbigniew Slipek, Mudryk Krzysztof
University of Agriculture in Krakow, Poland
marek.wrobel@ur.krakow.pl

Abstract. The paper proposes a model utilising the Artificial Neural Networks to describe the relationships of the unit contact surface of bean seeds as a function of their geometrical dimensions, load and water content. It has been proven that all factors assumed affect the output variable which is the unit contact surface of the seeds and flat surface. The experiments were performed on beans (*Jubilatka* specie) for six different water content levels in the seeds. The bean seeds were loaded with eight values of compression force (from 41 to 230 N). Five analyses were performed in parallel for each experimental combination. The neural model developed is a typical unidirectional network – four-layer perceptron with a large number of neurons in the hidden layers. ANN has preserved its generalisation ability – the average relative error 4.7 % for the testing data (not used in the teaching process).

Keywords: external friction, plant material, energy crops.

Introduction

The plant grain material is beds of seeds of crops, constituting a separate group belonging to a broad category of materials commonly referred to as loose materials. Due to three characteristic effects: the existence of static friction, inelastic collisions and practically zero energy of thermal movements, compared to the potential energy of the field of gravity, the loose materials are often considered as a separate state of matter [1]. The behaviour of such materials is a sum of a number of effects and interactions, some of them already known and described, and others still not yet recognised. The number of them is significant enough for results of tests of the physical properties of loose materials to be characterised by a great scatter [2].

Still, the phenomena occurring between the grain material (seed bed) and structural material are little known. This applies, among others, to the contact surface which is necessary to determine for many applications. The example can be the problem of determining contact stress values during the grain compression tests, determining the external friction force and modelling transport processes of grain materials [3]. Such research tasks require numerous experiments to be carried out, and are increasingly supplemented with simulation tests. Various types of models are applied, including those using the Artificial Neural Networks [4; 5].

Neural networks allow determining an effective model without the need to create theory, and, in a comparison of models utilising the ANN with the theoretic and empirical ones, the former appear to be more accurate. Application of the ANN allows also creation of models based on the measurement results with great random errors (processing distorted patterns) which, in case of biological material characterised by high variability of features and measuring difficulties, is one of the most important advantages of the networks. Furthermore, the artificial neural networks have the ability to generalise the knowledge acquired [3].

The objective of the research was to develop a model describing the relationship of the unit contact surface of bean seeds (defined as the actual contact surface of a single seed with a flat surface) as a function of the geometrical dimensions of the seeds, load and water content.

A model was created utilising unidirectional multi-layered Artificial Neural Networks. The basis adopted to create the model was the hypothesis:

$$S_j = f(F, Z, H, W, L) \tag{1}$$

where S_j – unit contact surface of a seed, mm^2;
F – pressure force on the seeds tested, N;
Z – water content in the seeds, kg·kg^{-1} dry mass;
H – seed thickness, mm;
W – seed width, mm;
L – seed length, mm.

Materials and methods

The tests were divided into two stages: the first – in which the contact surface was measured (according to a proprietary method developed by Frączek [6]), and the second – in which a proper artificial neural network was developed (according to the methods proposed by [7]). The first stage of the tests was completed according to the diagram shown in Fig. 1. The experiments were performed on beans (*Jubilatka* specie) for six different water content levels in the seeds. The bean seeds were loaded with eight values of compression force (from 41 to 230 N). Five analyses were performed in parallel for each experimental combination.

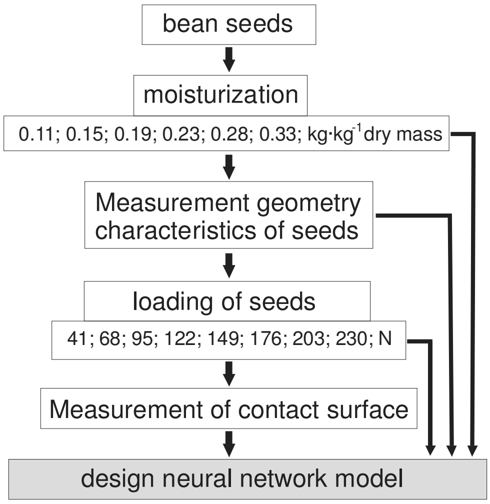

Fig. 1. **Diagram of the experiment**

Creation of the neural model, using Statistica Sieci Neuronowe v 6.0. software was performed in several stages [3]:

- preparing the data for neural networks – data acquired from the measurements were randomly divided into three sets: training (360 patterns), validation (180 patterns) and testing (180 patterns);
- creation of models and initial training of the artificial neural networks – an Automatic Designer in the Statistica software was used, 100 various types of neural networks were tested: linear networks (LIN) and multilayer perceptrons (MLP), from which 10 best models were selected;
- supplementary training of 10 best neural networks to increase the model operational accuracy; the backward error propagation (10000 epochs) and conjugate gradient method (5000 epochs) were applied for training;
- selection of the best model – as the selection criterion, the error measure MBw was applied for the validation set, which was defined as [3]:

$$MBw = |Bw| + sd(Bw), \tag{2}$$

where Bw – average relative error, %;
$|Bw|$ – absolute value Bw, %;
$sd(Bw)$ – standard deviation Bw, %.

Results and discussion

The measurement results of the unit contact surfaces for different load values and water content in the bean seeds are listed in Fig. 2.

The largest percent increase of the contact surface S_j occurred at the load 230 N and water content change from 0.11 kg·kg^{-1} dry mass to 0.33 kg·kg^{-1} dry mass. It was 684 %.

Analysing the plots, uneven growth of the contact surface values can be noted at some water content levels. The increments are due to various mechanical properties of the seeds.

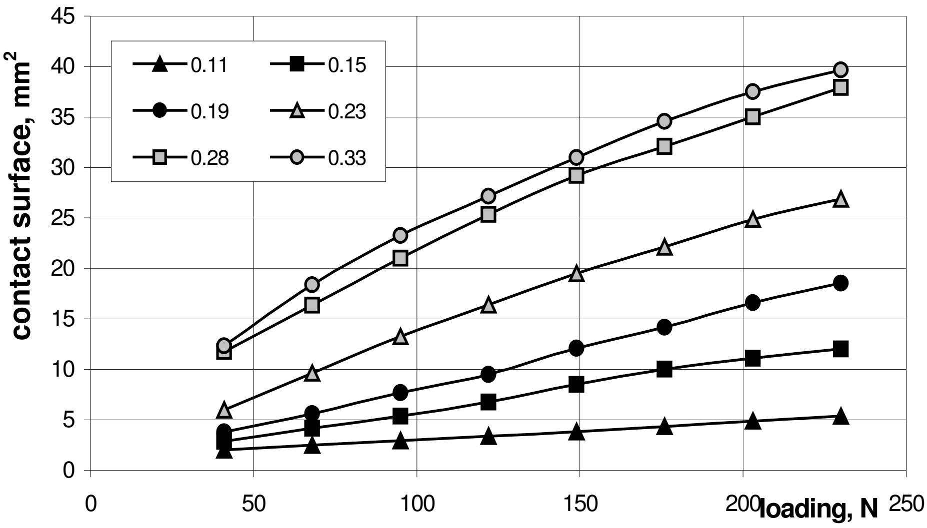

Fig. 2. **Change of the unit contact surface depending on the load at various water content levels in *Jubilatka* specie of beans**

Among the best 10 neural models, obtained in application of the Automatic Designer, only the multilayer perceptron (MLP) type networks are found – the networks are described in Table 1.

Table 1

Description of neural networks

Model	Type networks	Number of inputs	Number of neurons	
			Hidden layer 1	Hidden layer 2
ANN 1	MLP 5:5-10-8-1:1	5	10	8
ANN 2	MLP 5:5-10-8-1:1	5	10	8
ANN 3	MLP 5:5-7-1:1	5	7	0
ANN 4	MLP 5:5-9-1:1	5	9	0
ANN 5	MLP 5:5-10-9-1:1	5	10	9
ANN 6	MLP 5:5-10-8-1:1	5	10	8
ANN 7	MLP 5:5-9-1:1	5	9	0
ANN 8	MLP 4:4-10-8-1:1	4	10	8
ANN 9	MLP 5:5-10-6-1:1	5	10	6
ANN10	MLP 5:5-10-8-1:1	5	10	8

After the initial training stage, the *MBw* values were within the range from 50.7 % to 59.9 % (for the data from the validation set). The lowest values were obtained by the networks: ANN 9, ANN 8, ANN 5, ANN10, ANN 2 (four-layer perceptron) and ANN 3 (three-layer perceptron). Only the networks listed above were qualified for further training.

As a result of the supplementary training of the best models, reduction of the MBw value (Fig. 3) was achieved. It was found that the lowest *MBw* values for the validation set were achieved for the four-layer perceptron type network: sn09 (*MBw* = 29.7 %).

Error changes during the additional training of the neural network ANN 09 (for the training and validation set) are shown in Fig. 4, a. The training was performed in two stages: for 10000 epochs with the backward error propagation methods, and with the conjugated gradients method for other 5000 epochs. Analysing the training process, it can be concluded that no overtraining of the neural network occurred.

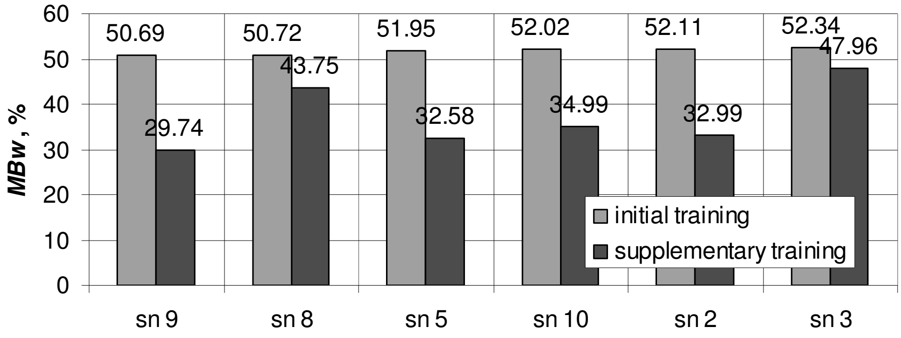

Fig. 3. ***MBw* measure values for the RFB and MLP networks after supplementary training (validation data)**

Fig. 4, b shows the values of the *MBw* measure for the best model (sn09 neural network), for the training, validation and testing sets. The lowest *MBw* values were achieved for the training data, slightly higher for the validation data and the highest for the test data.

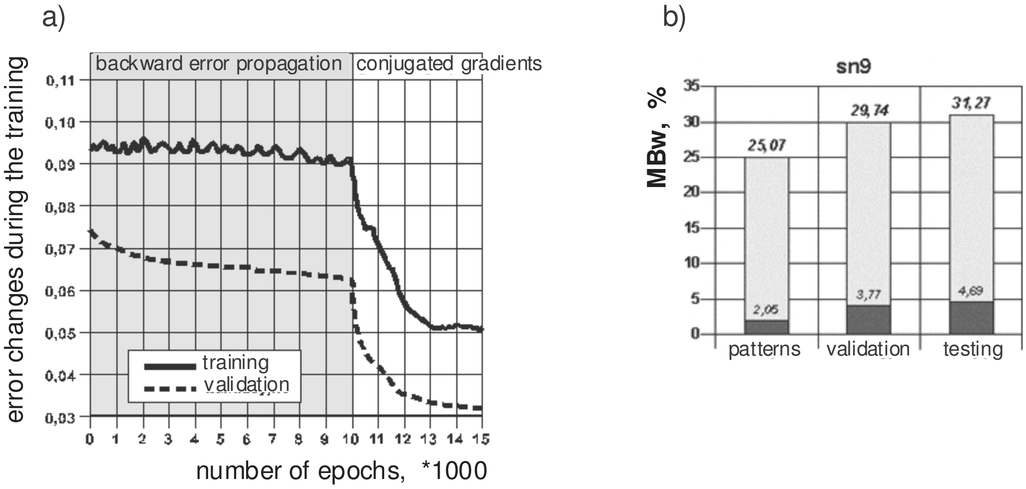

Fig. 4. **Supplementary training of ANN9 neural network:**
a – process; b – *MBw* measure values after the supplementary training

The structure of the neural model selected is shown in Fig. 5. The sn09 neural network is a four-layer perceptron with 10 neurons in the first hidden layer, 6 neurons in the second hidden layer and 1 neuron in the output layer. Values of five variables are given at the input: pressure, water content, thickness, width and length of a seed.

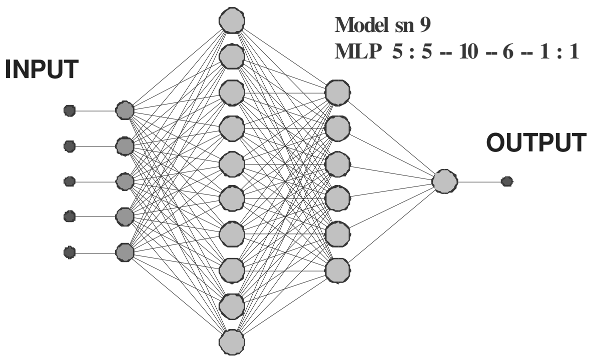

Fig. 5. **Neural model structure**

Conclusions

1. The sensitivity analysis performed proved that all input values assumed affect the unit contact surface – the output variable.

2. The neural model developed (sn 9) is a typical unidirectional network – four-layer perceptron with a large number of neurons in the hidden layers.
3. The sn 9 neural network has preserved its generalisation ability - the average relative error 4.7 % for the testing data (not used in the teaching process).
4. Additional training of the neural networks proposed by the Automatic Designer allowed considerable increase of the model accuracy (for the sn 9, MBw value changed from 50.69 % to 29.74 %).
5. In spite of additional training of the neural networks for 15000 epochs, no network overtraining was observed.

References

1. Mohsenin N. N. 1970. Physical properties of plant and animal materials. Gordon and Breach Science Publ. 1970, New York.
2. Ślipek Z., Kaczorowski J., Frączek J. 1999. Theoretical and experimental analysis of vegetable materials friction (In Polish). PTIR 1999. Kraków
3. Francik S., Frączek J., Ślipek Z. 2005. The use of artificial neural networks for cereal grain contact surface modelling. II International Scientific Conference: Information Technologies and Control Engineering in Management of Production Systems. Prague 20-22 September 2005, tome I, pp. 52-59.
4. Francik S., Frączek J. 2001. Model development of the external friction of granular vegetable materials on the basis of artificial neural networks. Int. Agrophysics 2001, 15, pp. 231-236. ISSN 0236-8722.
5. Złobecki A., Francik S. 2001. Defining the damaging process of cereal grains on the basis of artificial neural network. Int. Agrophisics, 2001, 15, pp. 219-223.
6. Frączek J. 2002. Relationship between real and unitary contact surface of cereal grains (in polish). Inżynieria Rolnicza 2002, vol. 6(39), pp. 143-148.
7. Ślipek Z., Francik, S., Frączek J. 2003. Methodic aspects of creating ANN models in agrophysical research (in Polish). Acta Agrophysica 2003, 2 (1), pp. 231-241. ISSN 1234-4125.