JOURNAL OF SUSTAINABLE MINING 14 (2015) 101–107

HOSTED BY
ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/jsm

Suitability assessment of artificial neural network to approximate surface subsidence due to rock mass drainage

*Ryszard Hejmanowski, Wojciech T. Witkowski**

Faculty of Mine Surveying and Environmental Engineering, AGH University of Science and Technology, Kraków, Poland

ARTICLE INFO

Article history:
Available online 14 August 2015

Keywords:
Subsidence
Drainage of underground mine
Artificial neural networks
MLP

ABSTRACT

Based on the previous studies conducted by the authors, a new approach was proposed, namely the tools of artificial intelligence. One of neural networks is a multilayer perceptron network (*MLP*), which has already found applications in many fields of science. Sequentially, a series of calculations was made for different *MLP* neural network configuration and the best of them was selected. Mean square error (*MSE*) and the correlation coefficient *R* were adopted as the selection criterion for the optimal network. The obtained results were characterized with a considerable dispersion. With an increase in the amount of hidden neurons, the *MSE* of the network increased while the correlation coefficient *R* decreased. Similar conclusions were drawn for the network with a small number of hidden neurons. The analysis allowed to select a network composed of 24 neurons as the best one for the issue under question. The obtained final answers of artificial neural network were presented in a histogram as differences between the calculated and expected value.

1. Introduction

Exploitation of deep-lying minerals is accompanied by adverse transformations in the ground surface. In addition to the direct effects associated with the resulting post-exploitation void, indirect effects can be distinguished, which include i.a. rock drainage. Formed on the surface of the ground, the so-called drainage basin is usually summed with the direct effects. The subsidence observed on the surface are the sum of these two types of interactions. In the analyses of transformations effects and subsidence forecasts, indirect influences are often omitted due to the low values of these type of subsidence occurring in the vast time horizon. A difficult issue is also the very process of forecasting dewatering-induced changes associated with the complexity of the problem of aquifers compaction.

In the world literature a variety of approaches to modelling this problem, not only in mining areas can be found. A thorough discussion of the existing methods of computation has been included in the publication *"Review of computational models using to subsidence prediction due to fluid withdrawal"* (Witkowski, 2014). An overview of the existing solutions and their usefulness in the prediction process of ground surface and rock mass displacements caused by drainage of water-bearing horizons is presented there. The simplest of the

* Corresponding author. Tel.: +48 12 617 45 02; fax: +48 12 617 22 87.
E-mail address: wojciech.witkowski@agh.edu.pl (W.T. Witkowski).
Peer review under responsibility of Central Mining Institute in Katowice.
http://dx.doi.org/10.1016/j.jsm.2015.08.014

cited approaches are empirical methods, which by using the information about the current state of surface deformations allow subsidence prediction in the short term. However, they do not take into consideration physical and mechanical properties of the individual layers of the rock mass. Semi-theoretical models are slightly more complex. They use fundamental physical parameters describing the aquifers. The calculations are based on generalized information about the geological conditions without taking into account the complexity of the compaction process of compressible layers. Another approach that can be distinguished in the prediction of drainage changes is hydrogeological modelling, in which the problem of fluid flow and rock medium deformations is perceived theoretically. Such a solution in a complete manner describes the phenomenon and does not require large amounts of measurement data, but also adopts assumptions simplifying the complex nature of compaction phenomenon. Repeatedly, the computational process must be preceded by the calibration of the theoretical model formed for the local geological conditions. Another of the approaches to the issue are solutions based on the theory of influence functions. However, they also adopt considerable simplifications and require the appointment of local values of the theory parameters based on geodetic survey data.

With this critical overview of the existing solutions follows the concept of employing a different approach to the prediction of dewatering-induced changes. Treating the compaction process as complex and difficult to describe thoroughly, using classic methods of calculation, it has been decided to use methods of artificial intelligence. Testing the concept outlined above will enable the verification of the working thesis. In the light of this thesis, the mathematical tools, which are artificial neural networks can be regarded as universal approximators that can successfully reproduce the compaction process of aquifers.

In this paper, it has been decided to use a multi-layer perceptron (*MLP*) network to set large-surface approximation of drainage basin in the area of one of the Polish underground mines. The task which was given for the network was to process measurement information to determine the mapping process.

2. Methods

Knowledge of the construction and operation of the human brain has allowed the development of a separate field of science called artificial intelligence. Widely developing branches are i.a. artificial neural networks, which are successfully used in engineering problems (Tadeusiewicz, 1993, 2013). Each network consists of single neurons of different types and structure. In 1943, one of the first models of the *McCulloch-Pitts* neuron (Osowski, 2006) was formed, which sums input signals x_i to the neuron with appropriate weights w_i and compares them with the assumed threshold w_{i0}. Output signal y_i is expressed by:

$$y_i = f\left(\sum_{i=1}^{N} w_i x_i + w_{i0}\right) \tag{2.1}$$

Function f is called activation function, which in the model of the *McCulloch-Pitts* neuron adopts the form of step-function:

$$f(u) = \begin{cases} 1, & u > 0 \\ 0, & u \le 0 \end{cases} \tag{2.2}$$

Similarly as in a nerve cell, the sum of all excitations must be greater than the threshold of a nerve cell activation. Only in this case, an electric signal can be sent in the form of a nerve impulse. Likewise, in the presented neuron model, the appropriate product sum of signals and weights can allow the activation of the neuron as an output signal $y_i = 1$. In addition to the presented neuron, there are a number of other models such as neurons of sigmoidal, radial, the Adaline, instar and Grosseberg's outstar, the WTA and Hebb type as well as stochastic model of a neuron. The most popular model from the utilitarian point of view is the sigmoidal neuron with a continuous function with unipolar activation in the form:

$$f(x) = \frac{1}{1 + e^{-\beta x}} \tag{2.3}$$

or a bipolar function in the form:

$$f(x) = tgh(\beta x) \tag{2.4}$$

where β is a parameter selected by the user and determines the shape of the activation function.

Only a juxtaposition of many neurons in a coherent system creates an artificial neural network and determines its ability to process signals similarly to the human body. Depending on the way of signal flow through the structure, one-way or recursive networks with the so-called reciprocal action be distinguished. Among the many existing models of neural networks, the most popular can be considered the one-way, multi-layered artificial neural network with sigmoid activation function also known as multi-layer perceptron (MLP) network. The most important problem in creating a network is an optimal choice of connection weights between neurons. They contain all the acquired and generalized “knowledge”. The most optimal selection of weights takes place in the process of network learning. It can occur in two variants, supervised learning (with a teacher) or unsupervised learning (without a teacher). The first method is performed by comparing the responses from the network with pre-set, expected values. On their basis the objective function is minimized. Adoption of continuous activation function allows the use of gradient network learning methods such as steepest descent method, variable metric algorithm and *Levenberg–Marquardt* algorithm considered the most effective in the artificial neural networks learning (Osowski, 2006). Properly trained network is able to generalize the acquired knowledge. It can be said that in this way the network becomes a universal approximator of several variables function, realizing some nonlinear mapping of input vector $\boldsymbol{x}$ into the expected response vector $\boldsymbol{y}$:

$$\boldsymbol{y} = f(\boldsymbol{x}) \tag{2.5}$$

In the engineering problems, artificial intelligence is used for such issues as approximation and interpolation, pattern recognition and classification, data compression, prediction, control and identification (Osowski, 2006; Tadeusiewicz, 2013).