AN ADAPTIVE CONTROL SYSTEM OF ROADHEADER WITH INTELLIGENT MODELLING OF MECHANICAL FEATURES OF MINED ROCK

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Abstract

An idea of use of artificial intelligence technology for determination of selected parameters of roadheader operation, by a direct implementation of artificial neural network in control system of machine, was presented in the paper.

The roadheaders operates in hard coal mines underground in extremely difficult environmental conditions. Technological process of driving of roadheader depends on many factors such as technical parameters of machine, mechanical and physical properties of rocks and operator's skills. It is difficult to develop a conventional system that could help in control operation of actuators of the machine, and increase the utilization of machine technical potential and improve rate of roadway development advance, due to mining-and-geological conditions (including mechanical and physical features of rocks), which are variable during mining.

Proposed system for control of roadheader, as an adaptive system equipped with artificial neural network, will react to changes in operational space of machine. Improved machine performance will be possible due to use of artificial intelligence technology, which aids analysis of conditions of machine operation such as type of mined rock, size of excavation or web depth, makes possible inference process of introducing adequate changes of actuators control values.

Keywords: *roadheader, artificial neural networks, rocks properties, control system*

1. Introduction

Use of non-renewable source of energy such as coal requires more and more difficult conditions of mining. Polish coal mines extract coal from deep seams what means difficult mining-and-geological and environmental conditions. Longwall mining system is the main system in Polish coal mines. The system enables high concentration of production and obtaining high outputs in the result of very high advance of face front. So, it is required that development and opening work is carried out with adequately high efficiency [4].

At present in the Polish coal mining industry over 92% (comparing with 2.3% in 1970) roadways are developed using the method of mechanical cutting by roadheaders. Forecasts for the nearest years assume the necessity of driving from 650 to 700 km of roadway per year [4].

Opening of coal seams on big depths requires bigger cross-section of driven roadways to ensure proper ventilation at elevated temperatures that increase with depth increase. Average rate of roadway's cross-section surface increase is about 2-2.5 m^2 per 10 years and average depth of mining, which now is 670 m, increases by about 10 m per year [4]. Together with mining depth increase also number of roadways with rocks of higher firmness and higher strength to uniaxial compression R_c [MPa].

Trends in world mining industry indicate for necessity of modification of roadheader's control system [3, 5, 7, 8] to improve its efficiency in roadways development operations. Due to safety reasons the best solution is to withdraw the personnel from the area of roadheader operation and to control roadheaders operation remotely, but considering necessity of installation of roadway support such a solution is difficult to be realized.

2. Rock's compressive strength

Rocks are tested for compressive strength in hydraulic presses and the strength is calculated according to the relationship 1.

$$R_c = \frac{P}{F}[N/m^2][MPa], \quad (1)$$

where:
P – compressing force [N],
F – average of two surfaces on which the force acts [m^2].

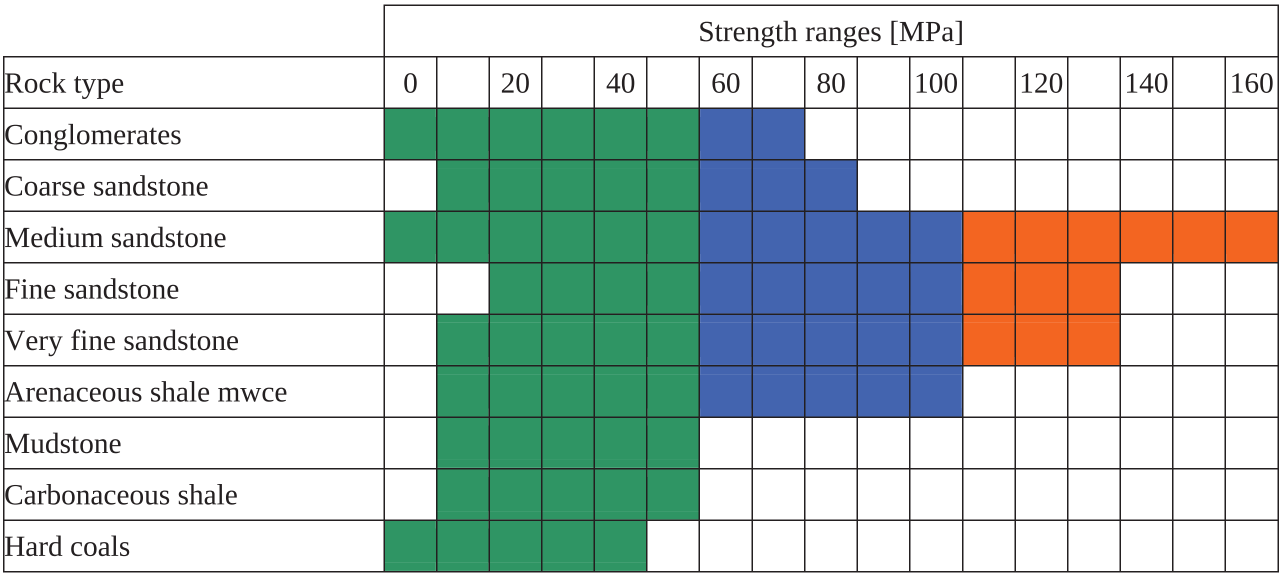

Fig. 1. Compressive strength Rc of carboniferous rocks [1]

2.1. Roadheader

Roadheaders are the main machines in mechanical systems for roadways development. The machines can be divided into three categories [1]:
- light - of weight up to 35 ton,
- medium - of weight up to 55 ton,
- heavy - of weight up to 55 ton.

In the Polish mines light roadheaders are most popular, about 70% of total number – including modifications of AM-50 roadheader, rarely medium weight roadheaders are used and only occasionally heavy ones. The roadheader realizes three main operations: cutting, loading and transportation of run-of-mine to other means of transportation.

The main components of roadheader are (Fig. 2): mining system – cutter jib with cutter heads (1), turning base (2), loader (3), stage loader (4), caterpillar chassis (5), hydraulic pack (6), electric equipment box (7).

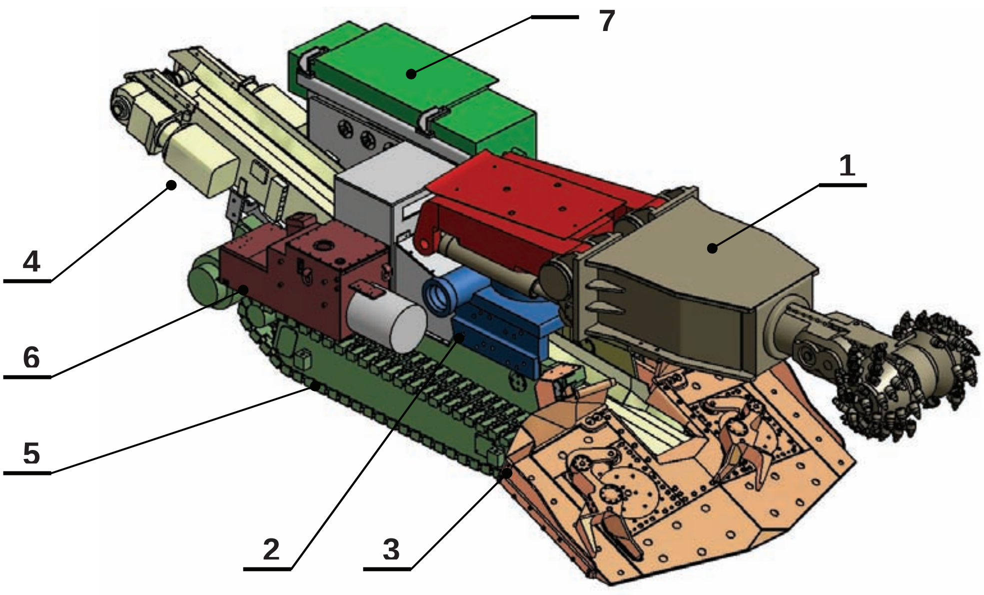

Fig. 2. Design of R-130 roadheader [1, 6]

Control of roadheader movements (apart of electric drives of advance system) is realized by the hydraulic system. Hydraulic pack is the main component of the control system. Control of cutting operation is realized by jib lifting cylinder and turning base cylinder.

3. Control algorithm

In the result of agreed assumptions, possibility of identification of R_c parameter of cut rock is a key feature of the adaptive control system. Layout of the control system is given in Fig. 3. This is a modification of the control system with model identification system (MIAS). It was assumed that maximal circumferential speed of cutter jib end (cutter head) $v_{ow} \Rightarrow max$ will be the input to the control system. Module of neural identification of R_c parameter, in connection with a module for determination of speed, generates v_{ow1} signal, which is correction of the setpoint. Speed control is realized in a feedback loop.

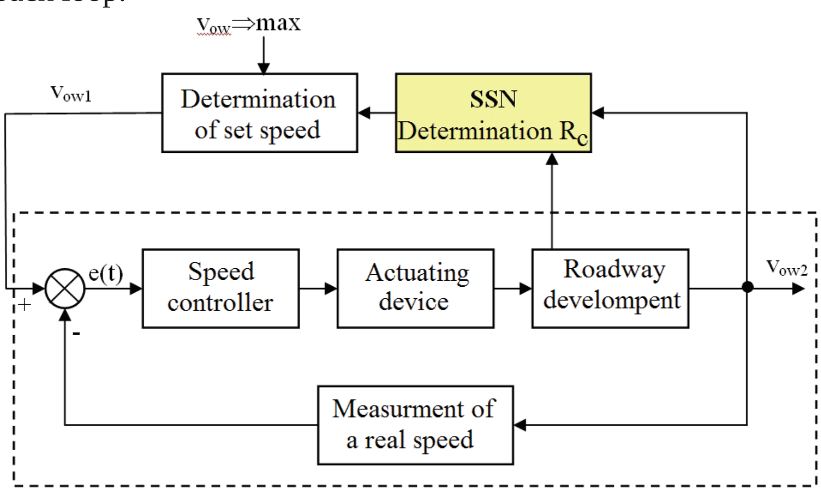

Fig. 3 Simplified diagram of jib speed control with use of Artificial Neural Network

Module of identification of model’s parameters was created using Artificial Neural Network. The Network was prepared using special independent computer application. The Network learning process was carried out with use of data collected during tests at Marcel Colliery.

4. In-situ tests

R-130 roadheader with measuring-and-recording instruments was installed in Marcel Colliery on a testing ramp M-6 in seam $707/_2$. The ramp was driven with ŁP9/V29/A support of frames spacing 0.75m. Width of a roadway was 5.0 m and height 3.5 m. Surface area of the support was 14.8 m^2.

At the face front, in the bottom part of roadway there was coal seam of thickness 1.4-1.6 m and of strength to uniaxial compressing equal to R_c=18.6 MPa, above there was a shale of thickness about 0.3 m and of strength to uniaxial compressing equal to R_c=30.9 MPa. At roof part of the roadway there was a sandy shale of thickness 1.6-1.8m and of strength to uniaxial compressing equal to R_c= 37.5 MPa. Floor of the roadway was made of sandy shale of strength to uniaxial compressing equal to R_c=37.5 MPa. Cross-section of driven roadway is presented in Fig. 4.

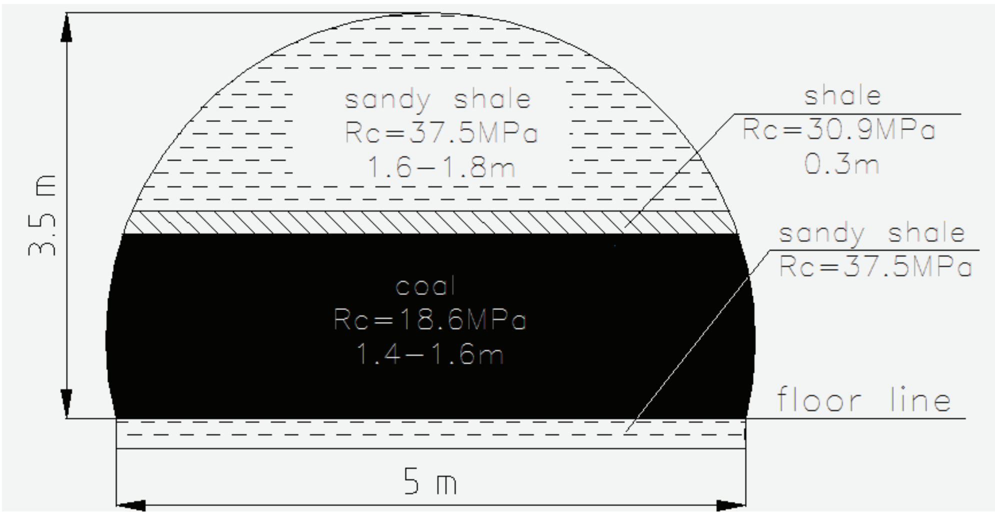

Fig. 4. Roadway cross-section during testing

Before the measurements it was agreed that presence of the specialist from KOMAG is required during the tests to observe and record all information as regards the technological process. The measurements were taken in four-shift system, the same as it is in the mine. The specialists wrote down the results of visual observation and events that have not been recorded by sensors (e.g. stop of operation due to necessity of manual break of coal block on a conveyor).

4.1. Learning data

Preparation of data used in neural networks often consumes more time than their further analysis [11]. Input data to neural network require processing as it is necessary e.g. to filtrate some amounts or to change their representation. Data preprocessing also has an impact on the speed of learning process. Diagram of data processing is shown in Fig. 5. Selection of data processing method is difficult and it is strictly associated with the problem to be solved what results in lack of clear guidelines for the procedure.

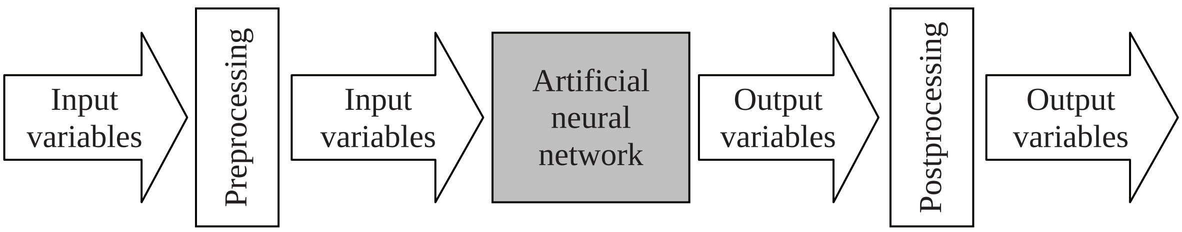

Fig. 5. Stages of data processing during neural modeling [11]

Preprocessing transformations among others should include:

- reduction of input data uncertainty level (data filtration to remove errors and data that is not true, reduction of disturbances as well as complementation of missing data),
- proper representation of input data, normalization, standardization and data scaling,
- statistical analysis of data: summarizing statistics, analysis of values that differ much, analysis of conglomerations, visualization of different aspects of data, size of data set.

In the case of artificial neural network implemented in a real PLC controller, the transformations that can be executed by the central controller unit in a real time should be selected.

On the basis of analysis of measurements taken during tests in Marcel Colliery the following input parameters to the artificial neural network were agreed:

- cutting drum current I_O [A],
- efficient value of acceleration of mechanical vibrations A [mm/s^2],
- pressure in annular chamber of turning base P_{On} [MPa],
- pressure in over-piston chamber of turning base P_{Op} [MPa],
- jib's angle speed ω_{ow} [rad/s].

5. Artificial neural network

Unidirectional multi-layer networks (MLP Muliti-Layer Perceptron) are most popular in practical technical use [2, 10, 11].

A single neuron with many inputs and one output is the main element of neural network. Neurons process signals that they get according to the accepted function. The neurons have ability to learn resulting from ability of modification of weights coefficients called synaptic weights [10, 11]. Most popular model of neuron that is used for building MLP network is presented in Fig.6. A neuron sums up input signal multiplied by weights (aggregation of input data) and uses transition function to determine the neuron's output value [11]. Often a neuron has additional input (x_0) called bias, which value is constant and is 1.

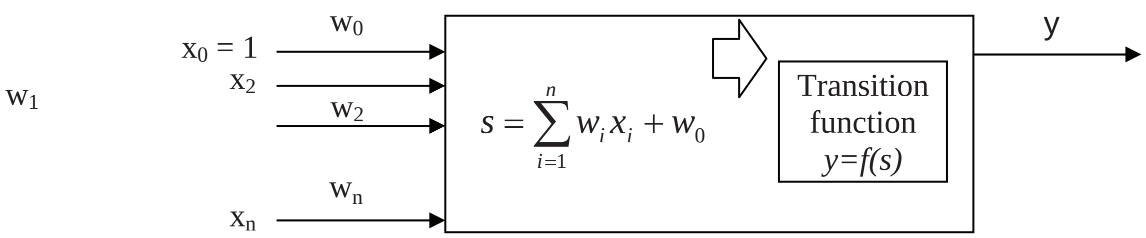

Fig. 6. Neuron structure [11]

Multi-layer, artificial neural network is created by connection of single neurons. In Fig. 7 the diagram of four-layer network consisting of input layer, two hidden layers and output layer, was presented.

Transition function (activation function, threshold function) connects sum of products of input signals of a single neuron and their weights (aggregated input value) with output signal. The simplest type of transition function is a linear function that is multiplication of input value by a constant coefficient. In practice sigmoidal function and hyperbolic tangent are used [5, 9, 10].

5.1. Results of model tests

Results of simulations indicate that MLP (Muliti-Layer Perceptron) of structure 5-9-5-1 (5 input neurons – 9 neurons in first hidden layer – 5 neurons in second hidden layer – one R_c output) is best in reflecting R_c value.

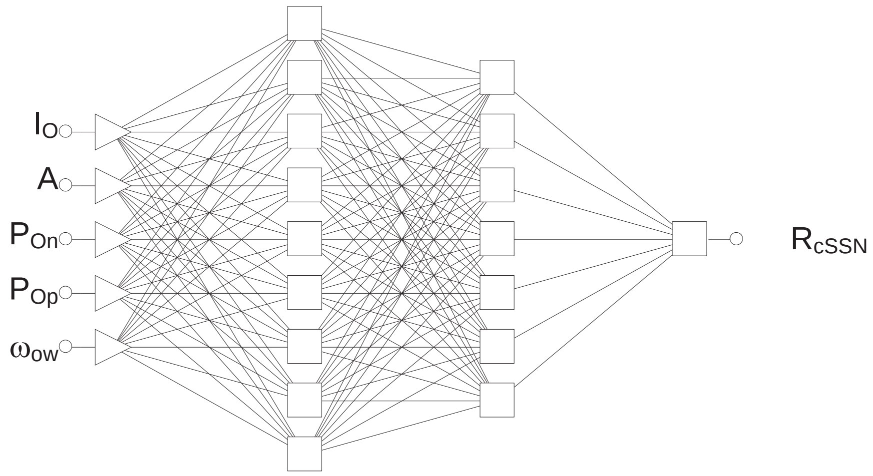

Fig. 7. Unidirectional multi-layer artificial neural network

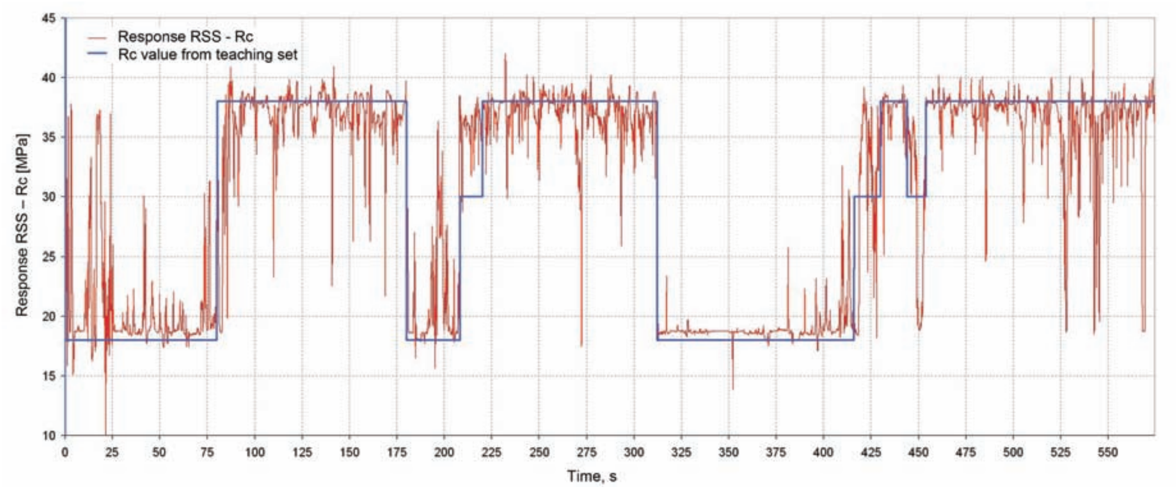

Fig. 8. Simulation results with Cykl20 MLP 5-9-5-1 network data

In Figure 8 diagram of network response in the case of learning data (blue line - the real R_c value, red line – the value generated by network) was presented.

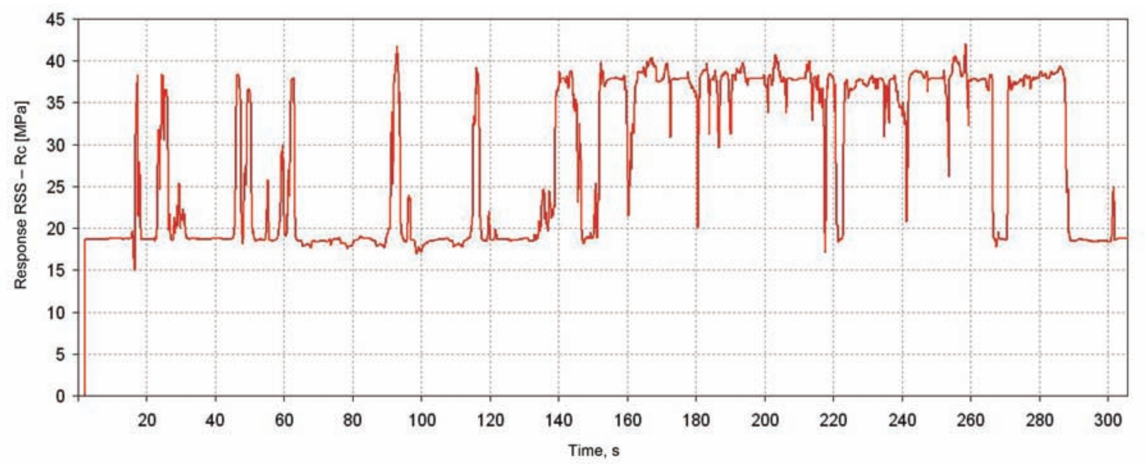

Fig. 9. Simulation results with Cykl18 MLP 5-9-5-1 network data

In Figure 9 diagram of network response in the case of selected real data recorded during testing in Marcel Colliery.

6. Summary and conclusions

The method of selection of circumferential speed of roadheader cutter jib v_{ow} in the plane parallel to the floor, depending on properties of cut rock – strength to uniaxial compression R_c, was developed within the project. To attain all objectives the artificial neural network was used at the stage of identification of R_c parameter.

The results obtained after implementation of artificial neural network enable to draw conclusion that algorithm is able to recognize R_c parameter of cut rock (we should state that data collected in tests that were used to train and test of artificial neural network, referred only to rocks of R_c=18 MPa and R_c=37 MPa). To improve the network operation it is necessary to extend measurement database by the measurements taken for other R_c parameters.

Experimental selection of coefficients in the formula that determines correlation among geometric parameters of mined layers, speed of cutter jib movement in plane parallel to floor and strength of rock to uniaxial compression, will be the next stage of the project. In the project relationships given in publications, referring to other types of roadheaders, were used.

Implementation and verification of operation of control system in real conditions will be the next stage of the project.

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