



**University of Belgrade
Technical Faculty in Bor**



**Chamber of Commerce
and Industry of Serbia**

XV International Mineral Processing & Recycling Conference



Proceedings

Editors:
Jovica Sokolović
Milan Trumić

**17-19 May
2023**

**Belgrade
SERBIA**



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RELATIVE PREDICTION ERROR OF FLOTATION INDICES BY ANFIS MODELS

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ABSTRACT – This paper describes performances of three different ANFIS models through the important statistical parameters – relative prediction error, its standard deviation and its mean. Copper content in the ore feed, collector dosage and frother dosage were selected as input parameters to estimate the copper grade and recovery in the final concentrate, and the copper content in the final tailings of the flotation plant. For each output parameter one ANFIS model is developed. Evaluation of the proposed models were performed on the basis of real process data collected by the multiannual monitoring of industrial flotation plant operation in “Veliki Krivelj Mine”. The results showed that the proposed ANFIS methodology is the most suitable for prediction of copper recovery in the final concentrate, given that the smallest relative prediction errors with their smallest standard deviation (SDE = 0.11) were obtained in this case.

Keywords: Flotation modeling, Relative prediction error, ANFIS.

INTRODUCTION

Adaptive Neuro-Fuzzy Inference System – ANFIS is an integration system in which neural networks are applied to optimize the fuzzy inference system. ANFIS constructs a series of fuzzy if–then rules with appropriate membership functions to produce the stipulated input–output pairs. The initial fuzzy rules and membership functions are first set by using human expertise about the outputs to be modeled. Then, ANFIS can modify these fuzzy if–then rules and membership functions to minimize the output error measure or explain the input–output relationship of a complex system. To describe the architecture of ANFIS, two fuzzy if–then rules are considered [1]:

Rule 1: If (x is A_1) and (y is B_1) then ($z_1 = p_1x + q_1y + r_1$),

Rule 2: If (x is A_2) and (y is B_2) then ($z_2 = p_2x + q_2y + r_2$),

where x and y are the inputs, A_i and B_i are the fuzzy sets, z_i ($i = 1, 2$) are the outputs within the fuzzy region specified by the fuzzy rules, and p_i , q_i , and r_i are the parameters determined during the training process. To implement these two rules, the architecture of ANFIS has five layers, as shown in Fig. 1.

It can be seen from the Figure 1 that the square stands for an adaptive node, and a circle indicates a fixed node. Nodes labeled with M are performed as multipliers, nodes

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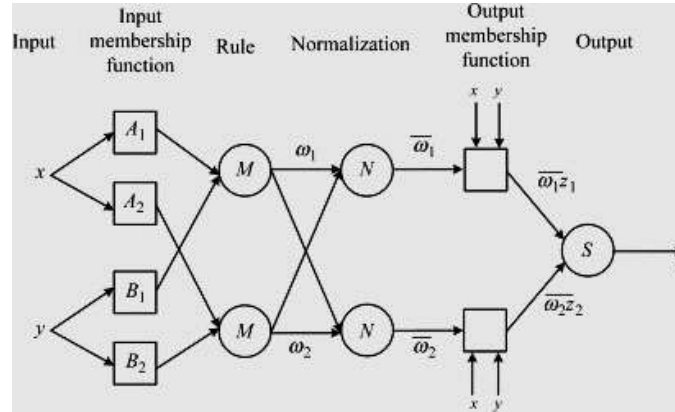


Figure 1 Architecture of the ANFIS [1].

labeled with N play a normalization role to the fuzzy strengths from the previous layer, where parameters ω_i represent fuzzy strengths. Single fixed node labeled with S represents output and performs the sum of the incoming signals [1].

EXPERIMENTAL

Experimental procedure was performed in virtual conditions, using the MATLAB programming language. A total of three models (which bear the labels ANF1, ANF2 and ANF3) have been developed using the ANFIS Editor Graphical User Interface. The independent variables in each model were: the copper content in the feed ore (FCU), collector dosage in the rough flotation stage (PXR) and dosage of frother (FRT). Other variables are considered constant due to different reasons (for more information see [2]) The dependent variables were: the final copper concentrate grade (CCU) in the ANF1 model; recovery of copper in the final concentrate (RCU) in the ANF2 model; and the final tailings grade (TCU) in the ANF3 model.

Model development and testing was based on the real process data, collected from the flotation plant "Veliki Krivelj" during the multi-annual monitoring. Performances of the proposed models were performed in Microsoft Excel through several statistical parameters that describe the validity of the model such as: correlation coefficient, determination coefficient, root mean square error, absolute error. Detailed description of the development of these models as well as a presentation of the mentioned statistical parameters is given in the literature [2, 3]. This paper deals with relative prediction error of these models, together with its standard deviation and its mean.

Relative prediction error (ϵ_r), serve as the criteria for evaluating the predictive properties of models, and is calculated according to the Formula (1):

$$\epsilon_r = \frac{Y-X}{X} \quad (1)$$

Where X is the measured value, Y is the predicted value.

Standard deviation of relative error SDE shows how much, on average, the elements of the dataset deviate from the arithmetic mean of that dataset and is expressed by

Formula (2):

$$SDE = \sqrt{\frac{\sum_{i=1}^n (x_i - \mu)^2}{n}} \quad (2)$$

where n presents the number of elements in the dataset, μ is mean (average value) of the dataset and x is the i -th member of the dataset.

RESULTS AND DISCUSSION

Relative prediction error can provide a good insight into the effectiveness of the predictive model, because it is used as a basis for comparing parameters that are expressed in different measurement units and different value ranges. Figure 2 present the relative prediction errors of the ANFIS models. The red lines on the charts represents mean (μ), green lines value $\mu + 1$ SDE and purple lines value $\mu - 1$ SDE. Table 1 presents values of SDE and μ for each model.

Table 1 Relative prediction error parameters using ANF1 ANF2 and ANF3 models

Statistical Parameter	Technological Indices of the Flotation Process		
	CCU	RCU	TCU
Standard deviation of relative prediction error, SDE	0.1995	0.1103	2.4568
Mean of relative prediction error, μ	0.0086	0.0785	1.7066

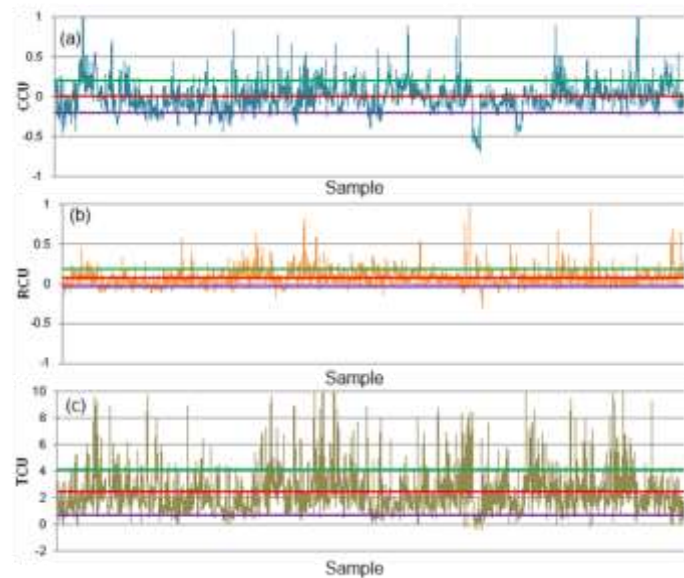


Figure 2 Relative prediction errors of flotation technological indices according to the (a) ANF1, (b) ANF2 and (c) ANF3 models

By visual analysis of the charts in Figure 2, it can be observed that the smallest relative prediction error is obtained when modeling RCU, and the highest when modeling TCU. The relative prediction error of ANF2 model has the smallest standard deviation (Table 1), and 79.3% of the results are in the range ± 1 SDE. When it comes to relative prediction errors of CCU and TCU, 75.6% and 78.2% of the results are within ± 1 SDE, respectively. A low standard deviation indicates that the values tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the values are spread over a wider range. It should also be noted that the TCU relative prediction error is mostly positive, which means that the values predicted by the model are, as a rule, slightly higher than the real ones (offset error). This result indicates that the additional fine tuning of the model is needed. Mean of the ANF1 model is the smallest ($\mu = 0.0086$), but this can be attributed to approximately the same number of positive and negative values of relative prediction error, which can be observed from Figure 2(a).

CONCLUSION

Performances of three different ANFIS models that predict copper flotation process indices (concentrate grade, tailings grade and Cu recovery in concentrate) are evaluated through their relative prediction error, its standard deviation and its mean. Evaluation of the proposed models were performed on the basis of real process data. The results showed that the smallest relative prediction error with the smallest standard deviation is obtained by applying the ANFIS predictive methodology to the Cu recovery variable. On the other hand, it turned out that this methodology is the least suitable for predicting of tailings grade.

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