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A fast and independent architecture of artificial neural network for permeability prediction

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ABSTRACT

Permeability is one of the most important parameters of the hydrocarbon reservoirs which represent and control the production and flow paths. Different direct and indirect methods try to measure this parameter which most of them, such as core analysis, are very time and cost consuming. Therefore, applying an efficient method which can model this important parameter is necessary. One of these methods which recently have been used frequently is artificial neural networks (ANNs) which have a significant ability to find the complex spatial relationship in the existence parameters of reservoir. Despite all of the applications of ANNs, most of them model the whole reservoir together and one should separate the different domains and use different networks. Also, most of them suffer from not using a priori knowledge or other source of data efficiently. Furthermore, the previous networks when encountering with very large dataset are slow and CPU demanding and they missed their accuracy when a few data are available. Therefore, all of these limitations lead us to use the modularity concept which is browed for biological system to address those problems. Thus, to mitigate these problems, a modular neural network (MNN) is presented. For this aim, one of Iran's oil field which contains three wells was selected for this application. Therefore, different multilayer perceptron and MNN were compared. In other words, the proposed method along four different architectures was used to predict the permeability and the obtained results were compared statistically. According to the obtained results when compared with traditional multilayer perceptron (MLP), this new method is promising very low computational time, the ability to encounter with complex problems, high learning capacity and affordability for most of the applications. The results show that the R^2 was improved from 0.94 to 0.99 for MLP and MNN networks, respectively.

1. Introduction

Permeability is one of the most important parameters in the petroleum reservoirs where its accurate value can have a great effect on production and management procedures. Therefore, we tried to use some direct measurements, such as experimental methods on cores, to find the permeability values. These methods are very useful, but they are not sufficient to show the heterogeneity of reservoir, because due to intensive time demanding and high cost, it is possible to drill only limited wells. Therefore, presenting a method by which can be able to predict the petrophysical properties, particularly permeability, is necessary. Also, another restriction can be due to unavailability of cores, missed cores in certain intervals and etc. which leads us to use some methods to predict them. Furthermore, most of the available logging tool operations cannot measure the permeability directly and one should interpret them. Also, several researchers tried to find a relationship between the widely available parameters in reservoir with permeability (e.g. depth and porosity) to reach the permeability indirectly, which one of these methods is nonlinear regression. However, these equations in the most of the conditions due to high reservoir heterogeneity are not reliable. For this aim, using a method which is able to predict the permeability in different heterogeneity conditions of reservoir is necessary.

In the recent years, the applications of artificial intelligent methods due to their intrinsic abilities to capture the nonlinearity and complex heterogeneity in reservoir have been widespread and can finds several applications such data mining, prediction, risk assessment, uncertainty quantification and data integration (Aminian et al., 2000; Aminian et al., 2001; Asadisaghandi and Tahmasebi, 2011; Ghezelayagh and Lee, 1999; Gorzalczany and Gradzki, 2000; Jagielska et al., 1999; Karimpouli et al., 2010; Mohaghegh, 1994; Mohaghegh et al., 2001; Nikravesh, 2004; Sahimi, 2000; Saemi and Ahmadi, 2008; Saemi et al., 2007; Tahmasebi and Hezarkhani, 2010a,b).

Among all of the artificial intelligent methods (e.g. artificial neural network (ANN), fuzzy logic (FL), genetic algorithm (GA)…), ANN due its flexibility and ability to solve the nonlinear problems, can find more applications. However, most of ANNs need a time consuming

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procedure of architecture design and the problem of local minima which leads the ANN to be used conservatively. Also, to escape of trapping the network in local minima, one can combine the ANN with GA (Tahmasebi and Hezarkhani, 2010a). In spite of wide applications and combinations of ANN, the efficiency of ANN will be decreased when encounter with a few data and/or very complex situation in which the data are very noisy and finding a spatial relationship is very difficult. Hence, the efficiency of designed network mostly depends on its the learning algorithm, topology and data distribution and these factors will change from one dataset to another one. Therefore, a significant amount of efforts and time should be consumed to find the optimum network.

One can assume the ANN as a optimization problem in which the variable are input–output, weights, learning coefficients (e.g. learning and momentum rate) and etc. that by using a learning algorithm that this problem can be solved that tries to achieve a network that can predict the output accurately. Therefore, it is possible to look at ANN as a procedure in which by adjusting some of parameters, the desired output should be resulted. Definitely, the convergence of optimization is tied with the number of variables and the availability of informative data to convey the complexity. Thus, if an optimization problem has a few data and/or a lot of variables, therefore, the optimization method cannot reach the global minima (or maxima) and it may be trapped in the local minima (or maxima). For this aim, one can reduce the involved variables in order to escape from local areas.

In the most of the previous studies, for solving the problem of local minima and the lack of data, they mostly combined the ANN with a global learning algorithm such simulated annealing or genetic algorithms. However, since these methods are iterative and for a good convergence need a lot of data, they themselves increase the complexity of the problem in the hand. Also, there is no clear attention to reduce the complexity of ANN.

The aim of this paper is to reduce the complexity of ANN by applying different structures of ANN to achieve some advantages. Also, it focused on finding an optimal architecture of network which can satisfy a network with low computational cost and can encounter with a situation in which we do not have a lot of data. Therefore, the main advantages of the current study can be summarized as follows. Due to an efficient complexity reduction in ANN, the code should be fast and have the ability to use a few examples and an escaping form of local minima.

One of the other aims of this paper is to introducing a new concept called modularity in petroleum industry by which one can achieve a lot of advantages. Furthermore, there is no related study in earth science about the use this type of ANN. The only related study is done by Tahmasebi and Hezarkhani (2010a) in which they modeled the complex spatial relationship in mining tasks for grade estimation.

The rest of this paper is organized as follows. In Section 2 the proposed methodology will be explained. Section 3 presents a case study by which the accuracy of the proposed methodology is evaluated. Section 4 describes the results and discussion including of some statistical comparison to show the efficiency of the proposed method and the results will be compared with the trial-and-error based ANN. Also, the paper is summarized in Section 5.

2. Theoretical background on ANN

2.1. Concepts

Artificial neural network (ANN) is a new tool which mimics the human's brain. Today, this tool has a variety applications in science, engineering, social science, economic and etc. Along with these applications, it has a lot of wide usage in oil industry.

One of first reasons which lead the researchers to investigate more about the human's brain was its parallel computing ability that let the brain to be better than the computers. After that, the nervous systems were studies widely. Mathematically speaking, one can assume the nervous systems of human as large number of elements which mainly arranged in different layers. A schematic description of this architecture can be seen in Fig. 1. According to this figure, one can see three main layers, input layer, hidden layers and an output layer. Therefore, the input signal will propagate through the layers which include a lot of elements and produce the output. Obviously, the main role of hidden layers is to find the spatial relationships between the input and output. Based on an iterative scheme and similar to human's techniques, the associated weights and biases will adjusted to produce the desired output. Therefore, the output response is a combination between the input, weights, biases and hidden layers elements. Also, in the hidden layer and output layer a function which mostly is the sigmoid function will be used to compute the output (Bean and Jutten, 2000). Obviously, the algorithm based on an assumed iteration and by calculating the produced error which is the difference between the real and estimated values will be continued. Finally, according to some predefined criteria such as the amount of error tolerance and/or number of iterations, the final network will be obtained (Bishop, 1995). Therefore, if the produced error was more the predefined error, the backward propagation accrued in which the weights should be changed in such a way the error was decreased.

2.2. Multi-layer perceptron (MLP)

MLP is one of the most prevalent feedforward ANNs which by using the described methodology in Section 2.1, the inputs maps to output. Usually, the internal layers of MLP are fully connected with each other.

Basically, there are two types of learning, supervised and unsupervised. It is clear that in a supervised learning procedure, the desired output for each of the training inputs is presented while in an unsupervised learning procedure the output is not provided. Also, the MLP uses a backpropagation (BP) technique for training the network which in essence is a kind of supervised learning methods.

Since, in this study we want to look at the ANN as an optimization problem, therefore, it is better to introduce the complexity in its learning. Usually, the error in ANN is measured by different criteria. One of these criteria is mean square error (MSE) that is defined by:

$$\varepsilon(n) = MSE = \frac{\sum_{i=1}^{n} (E_i - R_i)^2}{n}, \quad (1)$$

where E_i is the estimated value for a training vector of data i by network, and the R_i is the real value of data i and the n is the total number of available data for training.

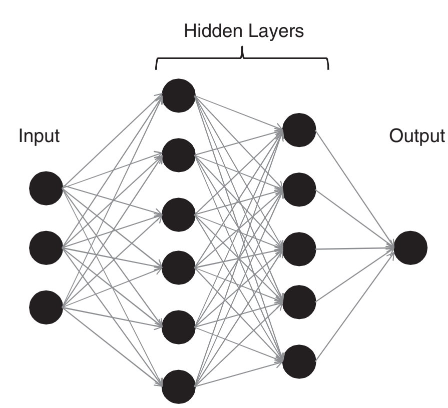

Fig. 1. MLP network with two hidden layers which shows the nested weight's vectors.