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A comparison study of using optimization algorithms and artificial neural networks for predicting permeability

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ABSTRACT

This paper presents a novel approach of permeability prediction by combining cuckoo, particle swarm and imperialist competitive algorithms with Levenberg–Marquardt (LM) neural network algorithm in one of heterogeneous oil reservoirs in Iran. First, topology and parameters of the Artificial Neural Network (ANN) as decision variables were designed without the optimization method. Then, in order to improve the effectiveness of forecasting when ANN was applied to a permeability predicting problem, the design was performed using Cuckoo Optimization Algorithm (COA) algorithm. The validation test result from a new well data demonstrated that the trained COA–LM neural model can efficiently accomplish permeability prediction. Also, the comparison of COA with particle swarm optimization and imperialist competitive algorithms showed the superiority of COA on fast convergence and best optimum solution achievement.

1. Introduction

Permeability prediction is one of the main challenges in reservoir engineering. On the other hand, suggesting engineering methods to solve reservoir modeling and managements is impossible without the knowledge of the actual permeability values (Biswas et al., 2003). The reservoir rock permeability cannot be measured directly with exception of using core plugs as direct measurement. However, direct measuring methods are expensive and time-consuming (Mohaghegh et al., 1997). In recent years intelligent techniques such as Artificial Neural Networks (ANNs) have been increasingly applied to predict reservoir properties using well log data (Mohaghegh et al., 1994). Moreover, previous investigations have indicated that neural networks can predict formation permeability even in highly heterogeneous reservoirs using geophysical well log data with good accuracy (Mohaghegh et al., 1996; Aminian et al., 2000).

In spite of the wide range of applications, a significant amount of time and effort has been expended to find the optimum or near optimum structure for a neural network for the desired task. To mitigate these deficiencies, design of neural networks using optimization algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) have been proposed (Boozarjomehry and Svrcek, 2001; Wang, 2005; Zhang et al., 2007; Kaydani et al., 2011).

Recently, a new evolutionary algorithm has been proposed by Rajabioun (2011), which was inspired by special lifestyle of cuckoo birds and was called Cuckoo Optimization Algorithm (COA). COA mimics the breeding behavior of cuckoos, where each individual searches for the most suitable nest to lay an egg in order to maximize the egg's survival rate, which is an efficient search pattern. Application of the COA in different optimization problems has proven its capability to deal with difficult optimization problems, especially multi-dimensional problems (Rajabioun, 2011).

In this study, the COA optimization and the LM algorithm were combined in order to form a two-stage learning algorithm for optimizing the parameters of the feed forward neural network. The proposed method was applied in permeability prediction in one of the heterogeneous oil reservoirs in Iran. Then, the results of the hybrid model were compared with experimental measurements from a new well data to find the efficiency of the present algorithm. Moreover, the optimal network design was done with particle swarm optimization and Imperialist Competitive Algorithm (ICA) and their results were compared with cuckoo optimization algorithm on designing neural network structure with LM training algorithm.

2. Artificial neural networks

Artificial neural network (ANN) is an especially efficient algorithm to approximate any function with finite number of discontinuities by learning the relationships between input and output vectors (Ganguly, 2003; Richon and Laugier, 2003). Feed forward type neural networks have an input, an output and, in most applications, have one hidden layer. The number of inputs and outputs of the neural networks are determined by considering the

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characteristics of the application. Each neuron of a layer is generally connected to the neurons in the proceeding layer. A neuron has two components: (1) a weighted sum, which performs a weighted summation of its inputs with components (X_1, X_2, X_3, …, X_n), i.e., $S=\sum W_i X_i + b$, where b is the bias of the networks; and (2) a linear, nonlinear or logic function, which gives an output corresponding to S. In general, the output from neural j in layer k can be calculated by the following equation:

$$u_{jk} = F_k\left(\sum_{i=1}^{N_{k-1}} w_{ijk} u_{i(k-1)} + b_{jk})\right) \quad (1)$$

Coefficients w_{ijk} and b_{jk} are the connection weight and bias of the network, respectively; they are the fitting parameters of the model and F_k is the transfer function of layer k. The output of the network is created at the output layer. Then the network's output pattern is compared with the target vector according to Mean Squared Error (MSE). The MSE of the neural network can be defined as follows:

$$MSE = \frac{\sum_{i=1}^{n}(O_i - T_i)^2}{n} \quad (2)$$

where O_i is the desired output, T_i is the network output, and n is the number of data in the training data set or the cross validation data set (Demuth et al., 2006).

For neural networks based on supervised learning, the data are usually split into a training set, validation set, and a test set. Various networks are trained by minimization of an appropriate error function defined with respect to the training set. Performance of the networks is then compared by evaluating the error function using the training and validation set, and the network having the smallest error with respect to the validation set is selected (Niculescu, 2003).

3. Optimization algorithms

In recent years, Evolutionary Computation (EC) and metaheuristis optimization algorithms have been a noticeable part for solving real mathematics and engineering problems. In the next sections, we describe some of optimization algorithms, which were used in this study.

3.1. Cuckoo optimization algorithm

Cuckoo Optimization Algorithm (COA) is a new evolutionary optimization method, which is inspired by the life of a bird family, called Cuckoo. Special lifestyle of these birds and their characteristics in egg laying and breeding has been the basic procedure of this evolutionary optimization algorithm. Like other evolutionary algorithms, it starts with an initial population including mature cuckoos and their eggs. The effort to survive among cuckoos constitutes the basis of COA. During the survival competition some of the cuckoos or their eggs, are destroyed. The survived cuckoo societies immigrate to a better environment and start reproducing and laying eggs. Cuckoos' survival effort hopefully converges to a state in which there is only one cuckoo society, all with the same profit values.

Each variable in this algorithm can be interpreted as a habitat, which is equivalent to chromosome in GA or particle in PSO algorithm. In N variable optimization problem, the habitat array is defined as follows, which represents the current position of variables (Rajabioun, 2011):

$$habitat = [X_1, X_2, \ldots, X_{Nvar}] \quad (3)$$

The profit of a habitat is obtained by evaluation of profit function f_p at a habitat, so

$$profit = f_p(habitat) = f_p(X_1, X_2, \ldots, X_{Nvar}) \quad (4)$$

from this point of view, the entire algorithm searches to maximize a profit function. To use COA in cost minimization problems, one can easily maximize the following profit function:

$$Profit = -cost(habitat) = -f_c(X_1, X_2, \ldots, X_{Nvar}) \quad (5)$$

By nature, each cuckoo lays from 5 to 20 eggs. These values are used as the upper and lower limits of egg dedication to each cuckoo at different iterations. Another habit of real cuckoos is that they lay eggs within a maximum distance from their habitat, which is called Egg Laying Radius (ELR) and defined as (Rajabioun, 2011)

$$ELR = \alpha \times \frac{Number\ of\ current\ cuckoo's\ eggs}{Total\ number\ of\ eggs}(var_{\text{hi}} - var_{\text{low}}) \quad (6)$$

where var_{hi} and var_{low} are the upper limit and lower limit of variables respectively, and α is an integer, supposed to handle the maximum value of ELR.

Each cuckoo starts laying eggs randomly in some other host birds' nests within her ELR. Some of these eggs, which are more similar to the host bird's eggs have the opportunity to grow up and become a mature cuckoo. Other eggs are detected by host birds and are killed. When young cuckoos grow and become mature, they immigrate to new and better habitats. After the cuckoo groups are formed in different areas with the K-means clustering method, the society with the best profit value is selected as the goal point for other cuckoos to immigrate. Fig. 1 shows the movement of cuckoos towards the destination habitat. In this movement, λ and φ are the random numbers, which are defined by (Rajabioun, 2011)

$$\lambda \sim U(0,1) \quad (7)$$

$$\varphi \sim U(-\omega, \omega) \quad (8)$$

where ω is a parameter that constrains the deviation from goal habitat and a value of about $\pi/6$ (Radian) for ω results in a good convergence of countries to the global minimum.

There is always equilibrium in birds' population so a number N_{max} controls and limits the maximum number of live cuckoos in the environment, which can be the result of food limitations, and other environmental conditions. After some iterations, all the cuckoo population move to one best habitat with maximum similarity of eggs to the host birds and also with the maximum food resources. This habitat will produce the maximum profit ever. There will be least egg losses in this best habitat. Convergence of more than 95% of all cuckoos to the same habitat puts an end to

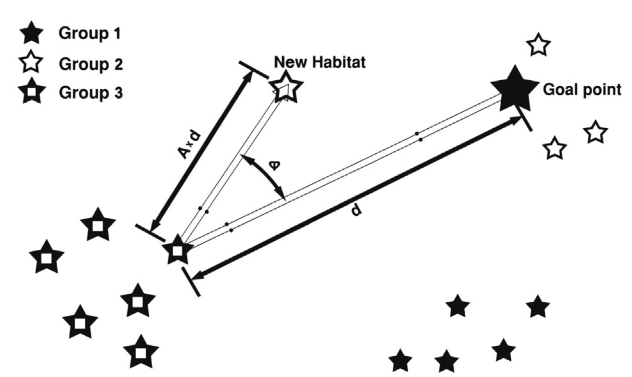

Fig. 1. Immigration of a sample cuckoo toward goal habitat (Rajabioun, 2011).