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Improved sensitivity based linear learning method for permeability prediction of carbonate reservoir using interval type-2 fuzzy logic system

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ABSTRACT

This paper proposed an improved sensitivity based linear learning method (SBLLM) model through the hybridization of type-2 fuzzy logic systems (type-2 FLS) and SBLLM. The generalization abilities of the SBLLM often rely on whether the available dataset is free of uncertainties to ensure successful result, which means that its generalization capability is sometimes limited depending on the nature of the dataset. Type-2 FLS has been choosing in order to better handle uncertainties existing in datasets and in the membership functions (MFs) in the traditional type-1 fuzzy logic system (FLS). In the proposed method, the type-2 FLS is used to handle uncertainties in reservoir data so that the cleaned data from type-2 FLS is then passed to the SBLLM for training and then final prediction using testing dataset follows. Comparative studies have been carried out to compare the performance of the proposed hybrid system with that of the standard SBLLM. Empirical results from simulation show that the proposed improved hybrid model has greatly improved upon the performance of the standard SBLLM.

1. Introduction

Hybrid computational intelligence is any effective combination of intelligent techniques that performs superior or in a competitive way to simple standard intelligent techniques. The increased popularity of hybrid intelligent systems in recent times lies in the extensive success of these systems in many real-world complex problems [1]. Also, it is an established fact that every approach has its strengths and weaknesses; hence the need for hybrid models that is able to combine the strengths of the individual techniques while complementing the weaknesses of one method with the strength of the other. Therefore, this work seek to take advantage of the unique capability of type-2 FLS, in modelling uncertainties, to improve the performance of the sensitivity based linear learning method (SBLLM) in order to further boost the generalization ability of SBLLM even in the face of uncertainties.

Sensitivity based linear learning method (SBLLM) has been recently introduced as a learning technique for two-layer feed forward neural networks based on sensitivity analysis that uses a linear training algorithm for each of the two layers [2]. It was introduced in order to alleviate some of the limitations of the classical artificial neural network (ANN). This algorithm tends to provide good generalization performance at extremely fast learning speed, while in addition, it gives the sensitivities of the sum of squared errors with respect to the input and output data without extra computational cost. It is very stable in performance as its learning curve stabilizes soon, and behaves homogeneously not only if we consider just the end of the learning process, but also during the whole process, in such a way that very similar learning curves were obtained for all iterations of different experiments [2,3]. Unfortunately, just like the classical ANN, SBLLM is unable to adequately model uncertainties in real life data. As a result of SBLLM inability to adequately handle uncertainties (including those in measurements and data used to calibrate the parameters), it will be a good contribution to seek to improve its performance through the use of type-2 FLS as its pre-cursor, in a hybrid arrangement, for uncertainty handling, in order to take advantage of its unique capabilities. Therefore in this paper, we propose a hybrid approach that will combine the unique attributes of type-FLS with those of sensitivity based linear learning

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method (SBLLM) by way of improving SBLLM performance in order to achieve better generalization ability in all situations including uncertainty oriented environment.

Type-2 fuzzy logic has been generally acknowledged as being better and ideal for uncertainty modelling [4–10] since it has been specifically invented to deal with different forms of uncertainties [10] that are inherent in our day to day natural encounters and mode of reasoning. Recently, type-2 FLS have been proposed as a novel framework for both classification and prediction in order to handle different forms of uncertainties [10,11]. It is able to handle uncertainties that include those in measurements and data used to calibrate the parameters. It has been used in several fields and the results have been promising and very encouraging with stable results [12–14]. Therefore, bearing in mind that there are uncertainties in reservoir characteristics and well log data [15], it becomes clearer that the best way to tackle this problem of uncertainty is to make use of type-2 fuzzy logic that is able to handle different forms of uncertainty [10]. Thus the significance of the proposed interval type-2 fuzzy logic based model cannot be overemphasized. In reality, allocating a crisp value to a real life choice or opinion is very unrealistic and very stringent unlike assigning an interval or range of acceptable values, which is better and more practical. Therefore, this paper propose an interval based approach to predict the permeability from oil well logs dataset using interval type-2 fuzzy inference systems. In the proposed approach, the grade of membership for a particular membership function to be taken on by any well log value or permeability value is not a crisp value but it is presented with a range of values that can be represented by a function that indicates the degree of uncertainties. The idea of using type-2 fuzzy logic systems in similar form as presented in this research is not strange but rather it has also been recently reported in knowledge based systems publications as in [16–24], in addition to other publications relating to unique applications of different techniques [25–39], often with promising results and outcomes.

Therefore, this paper investigate the feasibility of using type-2 FLS as a pre-cursor to improve the generalization ability of SBLLM in the face of uncertainty during prediction, in a hybrid framework setting. We develop a new hybrid model based on type-2 FLS and SBLLM and then use it for predicting permeability of carbonate reservoir, which is one of the most important oil and gas reservoir properties. We then investigated how the standard SBLLM compares, in its forecasting performance, with the proposed improved hybrid model. Empirical results from simulations demonstrated that the proposed hybrid scheme produced better generalization performance better than the standard SBLLM.

The rest of this paper is organized as follows. Section 2 presents a review of related researches and Section 3 presents the proposed hybrid model and its constituent parts. Section 4 contains the empirical study, implementation process, comparative studies, results and discussions. The conclusion and future work recommendations are provided in Section 5.

2. Related research

Permeability is one of the most important reservoir properties, and its prediction has been one of the fundamental challenges to petroleum engineers and researchers [40]. In general, permeability determination has been carried out using either empirical, statistical, or the recently introduced "virtual measurement' methods. Respectively, the researchers have utilized empirically determined models, multiple variable regression, and predictive computational intelligence paradigms in predicting permeability of reservoirs.

2.1. Empirical and statistical methods

These methods respectively make use of empirically determined models and multiple variable regression. The first equation relating measurable rock properties with permeability was proposed in 1927 by Kozeny and modified by Balan et al. [41]. Their formulations are valid only for packs of uniformly sized spheres. Another major drawback is that surface area can be determined only by core analysis, and only with special equipment. In 1941, Archie, in his classical paper [42], set the basis for quantitative log interpretation, though he did not provide a permeability formula. Analyzing the laboratory-determined resistivity of a large number of brine-saturated cores from various sand formations, Archie introduced the concept of "formation resistivity factor". In 1949, Tixier [43] established a method for determining permeability from resistivity gradients using empirical relationships between resistivity and water saturation, water saturation and capillary pressure, and capillary pressure and permeability. Other earlier works in this direction are those reported in [44–47,41].

Wendt and Sakurai [48] established a general procedure for permeability prediction by multiple variable regression. They also pointed out the shortcomings of using this technique. When the regression method is used for prediction, the distribution of predicted values is narrower than that of the original data set [41]. Despite all these efforts, permeability estimation has not been effectively handled with the desired accuracy due to various shortcomings of these empirical and statistical methods, hence the need to explore virtual measurement techniques for better results.

2.2. Virtual measurement technique

This is otherwise referred to as the computational intelligence or neural network based methods. There have been several variants of these methods, the most popular of which is the classical artificial neural network paradigms. Attempts have been made to utilize artificial neural networks (ANNs) for identification of the relationship which may exist between well logs and core permeability. However, despite the wide range of applications and flexibility of ANNs, there is still no general framework or procedure through which the appropriate network for a specific task can be designed [49].

One of the most popular works by Bruce et al. [50] presented a state-of-the-art review of the use of neural networks for predicting permeability from well logs. In the application, the neural network is used as a non-linear regression tool to develop transformation between well logs and core permeability. Such a transformation can be used for estimating permeability in un-cored intervals and wells. In the work, the permeability profile was predicted by a Bayesian neural network. The network was trained using a training set with four well logs (GR, NPHI, RHOB and RT) and core permeability. The network also provided a measure of confidence (the standard deviation of a Gaussian function) [50]: the higher the standard deviation ("sigma"), the lower the prediction reliability. This is very useful for understanding the risk of data extrapolation. The same tool can be applied to estimate porosity and fluid saturations. Another important application is the clustering of well logs for the recognition of lithofacies by Rogers et al. [51]. This provides useful information for improved petro-physical estimates and well correlation.

Abdelkader et al. [52] used artificial neural network and fuzzy logic to characterize naturally fractured reservoirs. Using these tools, they produced 2-D fracture intensity and fracture network maps in a large block of fields. The results showed that the proposed approach is a practical methodology to map the fracture network. The use of functional network was also reported by [53] for predicting permeability from well logs. Recently, application of fuzzy logic in petroleum engineering field has received considerable attention