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Shear wave prediction using committee fuzzy model constrained by lithofacies, Zagros basin, SW Iran

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A B S T R A C T

The main purpose of this study is to introduce the geological controlling factors in improving an intelligence-based model to estimate shear wave velocity from seismic attributes. The proposed method includes three main steps in the framework of geological events in a complex sedimentary succession located in the Persian Gulf. First, the best attributes were selected from extracted seismic data. Second, these attributes were transformed into shear wave velocity using fuzzy inference systems (FIS) such as Sugeno's fuzzy inference (SFIS), adaptive neuro-fuzzy inference (ANFIS) and optimized fuzzy inference (OFIS). Finally, a committee fuzzy machine (CFM) based on bat-inspired algorithm (BA) optimization was applied to combine previous predictions into an enhanced solution. In order to show the geological effect on improving the prediction, the main classes of predominate lithofacies in the reservoir of interest including shale, sand, and carbonate were selected and then the proposed algorithm was performed with and without lithofacies constraint. The results showed a good agreement between real and predicted shear wave velocity in the lithofacies-based model compared to the model without lithofacies especially in sand and carbonate.

1. Introduction

Shear wave velocity (V_s) plays a vital role in geomechanical studies and reservoir characterization in petroleum industry including petrophysical modeling, wellbore stability analysis, casing design, well planning, sand production and hydraulic fracturing. This parameter is obtained directly from core analysis in laboratory or downhole measurement such as dipole shear sonic imager (DSI) tools. Utilizing downhole measurement is an economical and general method in petroleum industries due to its advantages such as being nondestructive, continuous (in logging rock in reservoir condition), time-efficient and cost-effective compared to core analysis (Lacy, 1997). However, DSI is an expensive tool and is usually not recorded in many wells. Also, DSI information was not acquired in older wells due to lack of this technology. Therefore, finding out a quantitative formulation to estimate V_s is a very important task. In this regard many researches have been focused on establishing a relation between V_s and other rock properties obtained in laboratory or well logging (Castagna et al., 1985; Han, 1986; Anselmetti and Eberli, 1993; Eskandari et al., 2004; Brocher, 2005; Rezaee et al., 2006; Rajabi et al., 2009; Asoodeh and Bagheripour, 2012a,b; Bagheripour et al., 2015). Bagheripour et al. (2015) show intelligence-based methods performed better than empirical correlation in the prediction of V_s. Estimating V_s from conventional well logs has a good correlation with the measured values. However, this strategy has the main limitation of using post-drilling data and cannot be used for drilling forecasts. For overcoming this limitation, estimation of V_s from seismic data is a practical solution. Prestack inversion is used to convert seismic angle or offset data into shear impedance or velocity (Jin et al., 2000; Stewart et al., 2002; Hampson et al., 2005; Lu et al., 2015). Since pre-stack inversion methods are time-consuming and expensive and require specialist skills, using integrated post-stack data with an intelligence-based model could be an appropriate technique to estimateV_s.

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The aim of this research is to introduce a novel, available, easy, and inexpensive method for estimating shear wave velocity from post-stack seismic data. In this research upper cretaceous geological complex formation was selected from an oil field located in the SW of Iran. For this purpose, a committee machine based on fuzzy inference system (FIS) was established for formulating post-stack seismic attributes to V_s through a double-stage estimation. As can be seen in the flowchart shown in Fig. 1, initial V_s estimations are achieved from elements of committee machine including Sugeno's fuzzy inference system (SFIS), adaptive neuro-fuzzy inference system (ANFIS) and optimized fuzzy inference system (OFIS). The seismic attributes used as input data in this study were a set of physical attributes extracted from a post-stack seismic cube. Relative P-impedance was also considered as input since there was a pronounced correlation between shear and compressional impedance (Castagna et al., 1985). In this study, Relative P-impedance was obtained by a fast, easy and inexpensive inversion method called colored inversion (CI) based on Lancaster and Whitcombe (2000). The CI transforms the mean seismic spectrum into the mean impedance log spectrum by using an inversion operator. The CI's results and other seismic attributes were extracted at the well locations. Among them, best attributes were determined by step-wise regression as input for V_s estimation using fuzzy inference systems. Finally, a committee fuzzy machine (CFM) was utilized to combine all the results of earlier steps into the final output. The optimization method used in CFM is a new and powerful nature-inspired algorithm named bat-inspired algorithm (BA).

The introduced strategy was applied in an Iranian oil field in a clastics and carbonate reservoir. The method was performed with and without data classification. The classification of data was done based on lithofacies of sand, shale, and carbonate sediments in Kazhdumi, Dariyan, and Gadvan formations, respectively.

2. Method description

2.1. Bat-inspired algorithm

The BA is a nature-inspired algorithm proposed by Yang (2010) which uses the echolocation behavior of bats. The bats typically determine the size and position of preys by emitting loud sound impulses forward to objects and hear back the response that comes from them. In this algorithm the probable solutions are the positions (x_i) over which the bats randomly fly with velocity (v). Each bat releases sound and varies its loudness (A) and wavelength (λ) to discover a prey. Different frequencies (f) are drawn with a uniform distribution in the range of $[f_{\min}, f_{\max}]$ and are assigned to the bats. These frequencies, velocities and positions are updated during algorithm iterations. The random walk method is used to create a new solution in the updating process as follows:

$$x_{new} = x_{old} + \rho A^t, \quad \rho \in [-1, 1] \tag{1}$$

where ρ is a random coefficient and A^t is the average loudness of all bats at time t. As a bat gets closer to his prey, the loudness (A) decreases and pulse emission rate (r) increases in the following form:

$$A_i^{t+1} = \alpha A_i^t, \quad \alpha \in [0, 1] \tag{2}$$

$$r_i^{t+1} = r_i^0 [1 - \exp(-\gamma t)] \tag{3}$$

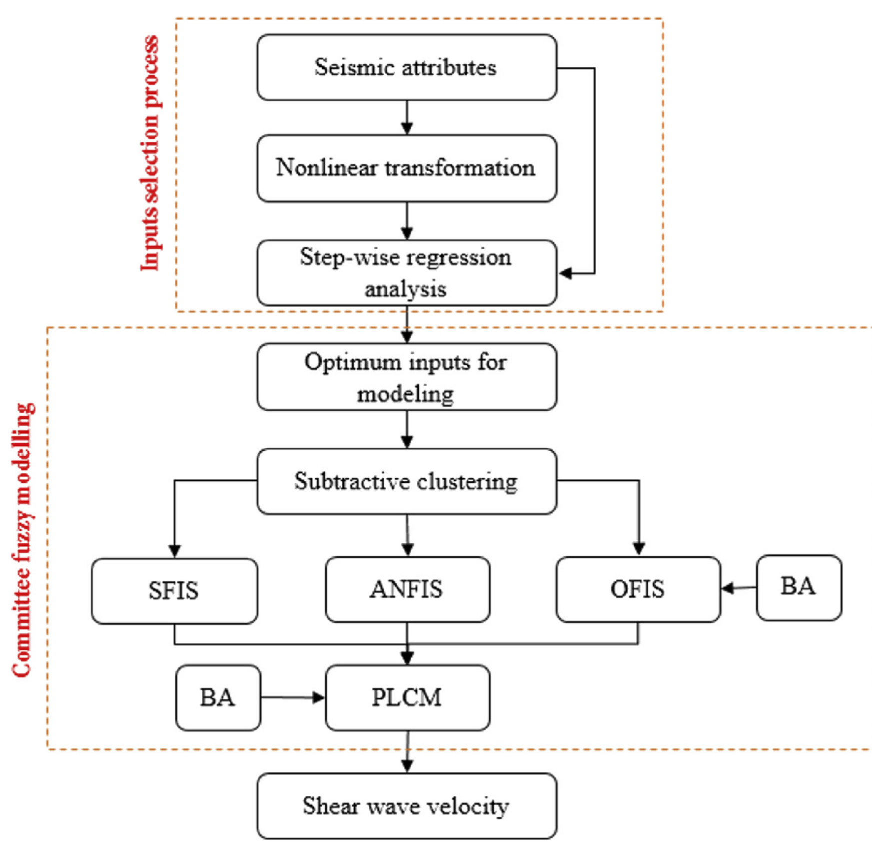

Fig. 1. Flowchart of the technique employed in this study.