Journal of Applied Geophysics 152 (2018) 1–8

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

A seismic fault recognition method based on ant colony optimization

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ARTICLE INFO

Article history:
Received 22 September 2016
Received in revised form 15 February 2018
Accepted 19 February 2018
Available online xxxx

Keywords:
Fault recognition
Ant colony optimization
Seismic section
Horizon

ABSTRACT

Fault recognition is an important section in seismic interpretation and there are many methods for this technology, but no one can recognize fault exactly enough. For this problem, we proposed a new fault recognition method based on ant colony optimization which can locate fault precisely and extract fault from the seismic section. Firstly, seismic horizons are extracted by the connected component labeling algorithm; secondly, the fault location are decided according to the horizontal endpoints of each horizon; thirdly, the whole seismic section is divided into several rectangular blocks and the top and bottom endpoints of each rectangular block are considered as the nest and food respectively for the ant colony optimization algorithm. Besides that, the positive section is taken as an actual three dimensional terrain by using the seismic amplitude as a height. After that, the optimal route from nest to food calculated by the ant colony in each block is judged as a fault. Finally, extensive comparative tests were performed on the real seismic data. Availability and advancement of the proposed method were validated by the experimental results.

1. Introduction

A fault is the part where the horizon is broken in seismic section. Fault recognition plays an important role in seismic interpretation and very meaningful in oil and gas exploration. Conventional fault recognition methods are very operator-intensive: fault is picked in seismic section as discontinuities of seismic amplitude. The drawback is that it greatly depends on the prior geological information and the experience of interpreter. Therefore, an automated approach to recognize fault from seismic data has been studied extensively.

The classic coherence cube algorithms (C1 to C3) which have gone through three generations of development are the earliest automatic fault recognition methods. Bahorich et al. proposed C1, fault was extracted by the correlation value between three seismic traces based on the classic normalized cross correlation (Bahorich et al., 1995). Marfurt et al. proposed C2, the number of seismic traces used in correlative computation was increased to multi-traces contained in a cuboid or ellipsoid (Marfurt et al., 1998). Gersztenkom et al. proposed C3, the eigenvalues of the covariance matrix of the seismic traces contained in analysis window were used for the computation of coherence attribute (Gersztenkorn and Marfurt, 1999). These widely used coherence algorithms have their own advantages and disadvantages. Experiments confirmed that C1 works faster, but, it is sensitive to the interference of coherent noise, C2 is better in accuracy and noise resisting compared with C1, however, it requires more computing work, C3 is more efficient compared with C2, however, the exact fault location can't be decided. Furthermore, mean effect is the common feature of C1 to C3 where lots of small faults are easily missed.

Gibson et al. proposed a fault recognition algorithm based on the highest confidence first strategy where the discontinuous properties are used to determine the mathematical model of a fault, then, the maximum reliability prior strategy is used for fault recognition (Gibson et al., 2003, 2005). The computational complexity of this method is too high. Wang et al. proposed a faults recognition method based on Hough transformation (Wang and AlRegib, 2014; Wang et al., 2014), the discontinuities were computed with C2 and the likely fault regions were highlighted by thresholding the discontinuities, then, Hough transformation was utilized for fault recognition (AlBinHassan and Marfurt, 2003; Gonzalez and Woods, 2008). This method can't work well when the number of the faults in a seismic section is greater than one. Based on the complex-value seismic trace proposed in Browaeys (2010), Wang et al. proposed a fault recognition method based on the directional complex-valued coherence attribute. By using the Hilbert transform of a real seismic trace as the corresponding complex-value seismic trace, they calculated the coherence value between adjacent weighted complex-value seismic traces along multiple azimuths, and considered the point with the minimum complex-value coherence attribute as a fault (Wang et al., 2016). However, the mean effect still

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https://doi.org/10.1016/j.jappgeo.2018.02.009

exists and some horizontal information is left. Soto-Pinto et al. presented a numerical method for automatic detection and analysis of changes in lineament patterns caused by seismic and volcanic activities (Soto-Pinto et al., 2013). Panagiotakis et al. proposed a framework for automatic enhancement and identification of the linear patterns of geological fault structures (Panagiotakis and Kokinou, 2015). However, these methods deal with the geographic data of the earth's surface, rather than the underground seismic data. There are many other methods also, such as Barna et al. (2015), Wang and Lu (2016), Yu et al. (2017), Randen et al. (2001).

Most recently, fault recognition methods based on ant colony optimization (ACO) have been proposed, the faults are recognized through ants creeping on fault-like points in seismic data (Randen et al., 2001; Pedersen et al., 2002, 2005; Yan et al., 2013). The micro fault can be recognized with these methods. However, many fault-like points which should be judged as horizon are mistaken as fault. In addition, this method has a high computational cost.

In order to improve the accuracy and reduce the time consumption, a new fault recognition method based on ACO (FRACO) has been proposed in this paper. Where the positions of the nest and food are located based on the endpoints of the horizons, then the three dimensional representation of positive seismic section is considered as actual terrain and the shortest route from nest to food searched by the ant colony is judged as a fault. The innovation of the proposed method is that we first time use the seismic section as three-dimensional terrain and recognize the fault through the ant's creeping on the terrain. The novelty work we performed in the paper can be applied to many fields such as seismic interpretation, petroleum exploration, building location, agriculture production and coal mining. Seismic data can be interpreted more correctly and oil, gas, coal and other resources can be explored more accurately are the reasons we published this work.

We start this paper with the description of the principle of the FRACO in Section 2. Then, real seismic data is used to illustrate the performances of the proposed FRACO for faults recognition through experiments and compares with traditional methods in Section 3. Finally, some conclusions are provided in Section 4.

2. Fault recognition method based on ACO

A. The principle of the ACO algorithm

The principle of the ACO can be interpreted by the "double bridge" experiment carried out by Gross et al. (1989). The schematic diagram of the "double bridge" experiment is shown in Fig. 1.

In the experiment, bridge A and B are placed between the nest and the food as shown in Fig. 1(a). After 4 and 8 min, the ant colony is distributed as Fig. 1(b) and (c) respectively. The results proved the ability of the ant colony to select the shortest route from nest to food.

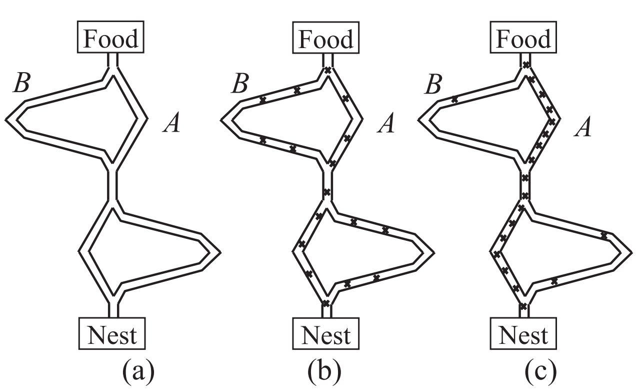

Fig. 1. Diagram of the "double bridge" experiment.

The mathematical model of the "double bridge" experiment is described by Eqs. (1)–(3) (Dorgio, 1992).

$$P_A(m+1) = \frac{(A_m+k)^h}{(A_m+k)^h + (B_m+k)^h} h \tag{1}$$

$$P_B(m+1) = 1 - P_A(m+1) \tag{2}$$

$$R(m+1) = \begin{cases} A, & \text{if } P_A(m+1) > P_r \\ B, & else \end{cases} \tag{3}$$

where m is the total number of the ants that have passed through the double bridges A and B. A_m and B_m are the number of ants that have passed through the bridge A and B respectively. $P_A(m+1)$ is the probability that the $(m+1)$th ant selects bridge A, $P_B(m+1)$ is the probability for bridge B. k and h are the parameters that are set according to the actual data, P_r is a random number between 0 and 1, the variable R is an array used to store the crawling route.

B. The application of ACO in seismic section

To recognize faults in a seismic section, we considered the section as a terrain where the ant colony are distribute on and the shortest route founded by an ant is judged as a fault. The procedure by which the seismic section is used as a terrain and the determination of the condition for the creeping of an ant are provided in this part.

1) Determination of the terrain based on seismic section

Both positive and negative amplitudes in a larger range are contained in a seismic section. Because the data type of the seismic amplitude is double-precision floating-point, it is inconvenient to use its three-dimensional presentation as a terrain directly. For that, we transform the seismic section to gray scale. The transformation method is described by Eq. (4).

$$x_g = \left({x_0 - S_{\min}} / {(S_{\max} - S_{\min})} \right) \times 255 \tag{4}$$

where, x_g represents the gray scale value, x_0 is the original seismic amplitude, $S_{\min}$ and $S_{\max}$ are the minimum and maximal amplitudes in a seismic section respectively.

The direct show and gray scale show of a seismic section are given in Figs. 2 and 3.

With sample time, trace number and seismic amplitude are used as the horizontal, longitudinal and vertical coordinates respectively, a seismic section can be represented in a three-dimensional coordinate system. By tessellating all seismic samples to a mesh, the three-dimensional presentation of the seismic section and that of the corresponding gray scale section are shown in Figs. 4 and 5.

Fig. 2. Direct show of a seismic section.