An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)
©2014 China University of Mining and Technology Press, Xuzhou, ISBN 978-7-5646-2437-8

Ordovician Limestone Aquosity Prediction Using EMD and Nonlinear Seismic Attributes

Yaping Huang[1], Shouhua Dong[1], Duoming Zheng[2], Huiwen Xie[2], Xuemei Qi[1]

1 China University of Mining and Technology, yphuang@cumt.edu.cn
2 Research Institute of CNPC Tarim Oilfield Co，zhengdm-tlm@petrochina.com.cn

Abstract Ordovician limestone water is the main source of water inrush in North China coal mines. Therefore, research of the aquosity of Ordovician limestone has great significance. In this paper, we present a method that integrates empirical mode decomposition (EMD) and nonlinear seismic attributes. Then we take the seismic data of XT coal mine as examples. The seismic data is decomposed by the EMD and then the nonlinear seismic attribute are extracted. Compared the results with transient electromagnetic exploration, they are basically consistent. Therefore, this demonstrated the method which integrates EMD and nonlinear seismic attributes is an effective approach to predict the aquosity of Ordovician limestone.
Keywords empirical mode decomposition, nonlinear seismic attributes, aquosity

Introduction

The mine water disasters has been one of the major mine disaster in coal mine production safety. China's coal resources are rich, coal mine hydrogeological condition is very complex, so that the mine water disasters have often occurred. Once the water inrush occurring, it will result in disastrous consequences for mine, so carrying out the research of Ordovician limestone water has the crucial significance.

Battista et al. used EMD as a filter for eliminating the impact of cable strum in seismic data (Battista et al. 2007). Bekara et al. devised a new filtering technique for random and coherent noise attenuation in seismic data by applying EMD (Bekara et al. 2009). Song et al. applied the EMD method for studying vertical displacement of internal waves in the northeastern South China Sea from seismic data (Song et al. 2010). Huang et al. used EMD to the seismic data of marine carbonate strata in southern China and identified the distribution of sedimentary facies(Huang et al. 2011). Li et al. studied the influence of transition IMF on EMD do-noising result, and proposes a method to remove the noise aliasing in the transition IMF (Li et al. 2013). Huang et al. (2009) extracted the nonlinear seismic attributes based on the 3D prestack migration seismic data and determined the possible Ordovician limestone aquosity distribution. Wen et al. applied the EMD and correlation dimension to predict reservoir combinations, achieved good results (Wen et al. 2009).

In this paper, firstly we introduced the basic principle of the EMD and the physical significance of nonlinear seismic attributes In addition, the actual data were used to examine the effeteness. Finally, the results show that the prediction of Ordovician aquosity based on EMD and nonlinear seismic attributes is feasible.

The basic theory

EMD

Hilber-thuang transform is suitable for nonlinear and non-stationary signal data processing and its core is the EMD (Huang et al. 1998). The EMD decompose the signals into different sets of basement and each decomposition result has its own adaptive characteristics. Hence, the method is more suitable for complex non-stationary signal processing. When seismic wave propagates in the stratum medium, the seismic signal belongs to the non-stationary signal. Therefore, the EMD can be used in the decomposition of seismic data. Huang thought that any signal is a series of different intrinsic mode functions (IMF) and the IMF satisfy the following conditions (Huang et al. 1998):

(1) In the whole dataset, the number of extreme points and the number of zero-crossings must either be equal or differ at most by one.

(2) At any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero.

For decomposition of the signal, empirical mode decomposition of the function process description is as follows:

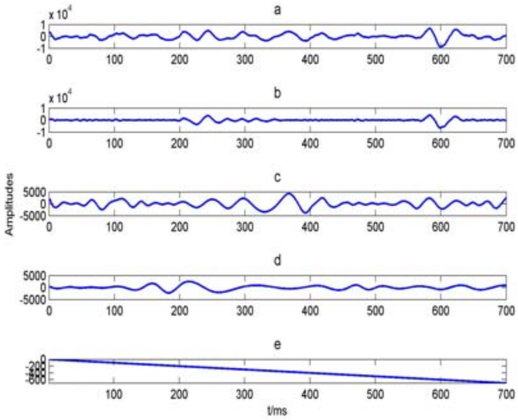
For any signal s (t)，first we determine all extrema points in the signal and then the maxima and minima points are linked by two curves that form the upper and lower envelopes containing all signal data. Let m (t) be the mean of the upper and lower envelopes and let the difference between s (t) and m (t) be h (t), h (t) = s (t) - m (t), we regard h (t) as a s (t), repeat these steps until satisfies the conditions of IMF, make c_1 (t) = h (t), c_1 (t) can be regarded as the first of the IMF,r (t) = s (t) - c_1 (t), make r (t) as new s (t), repeat the above process, in turn can get a series of the IMF, When r (t) extreme value point less than 2, stop decomposition. According to the above process, EMD decomposition of s (t) signal can be expressed as follows: $s(t) = \sum_{i=1}^{n} c_i + r(t)$.

Because the EMD of basic functions are different, the EMD not only improve the efficiency of signal decomposition, but also make this decomposition method more conducive to non-stationary data processing. Fig.1(a) is a seismic signal from a seismic data, fig. 1(b), 1(c) and 1(d) are obtained from the decomposition of the three IMFs and fig. 1(e) is a residue.

Fig.2 is the instantaneous frequency of signal in fig.1. And from fig.2, we can see that four IMF components corresponding to different frequency components of the signal from high to low frequency. Among them the instantaneous frequency of IMF1 is 30 to 150 Hz, which is main corresponding to the high frequency noise. However, the instantaneous frequency of IMF2 is 0 to 60 Hz, which is the dominant frequency range of basic consistent with seismic records. According to the literatures(Wen et al. 2009, Song et al. 2010, Huang et al. 2011), IMF2 corresponds to the main effective component in the seismic signal while the instantaneous frequency of IMF3 and residue is corresponding to the low frequency information in seismic records.

Nonlinear seismic attributes

Sedimentary basins are dissipative nonlinear dynamic systems and when reservoirs containing water, gas, and oil, the system will be complicated. The largest Lyapunov exponent on the complexity of the changes are more sensitive, so the largest Lyapunov exponent attribute can be used to predict the fracture zone and then further predict the aquosity of Ordovician limestone. Rock properties and their distribution in the earth exhibit strong, non-uniform anisotropy after a long era of multiple geological effects. Different seismic data fractal dimensions correspond to different lithology, fluid property, and reservoir parameters (Huang et al. 2009).



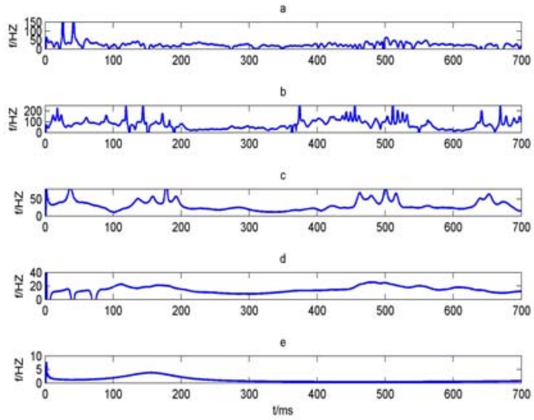
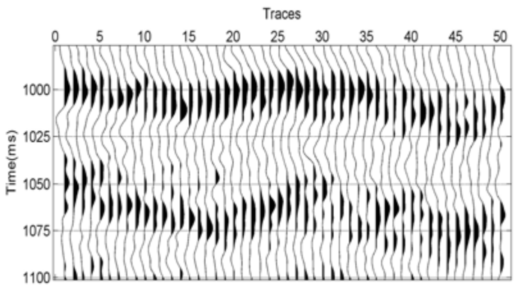


Fig.1 *Seismic record and its EMD data* ***Fig.2*** *The instantaneous frequency of fig.1*

The calculation steps of the largest Lyapunov exponent and correlation dimension have been described in detail in the literatures (Huang et al. 2009, Wen et al. 2009), so we not repeat them here. Fig.3 is an actual seismic profile of a seismic area, which shows that seismic wave energy between Trace5-Trace15 and Trace35-Trace50 are weak which is irregular. However, the other seismic traces have better regularity and stronger energy.

Based on above discussion, seismic records of IMF2 are corresponds to the main effective component in the seismic waves. We use EMD to process the seismic data of fig.3 to obtain the largest Lyapunov exponent and correlation dimension seismic attributes of the IMF2 signals which are shown in fig.4.



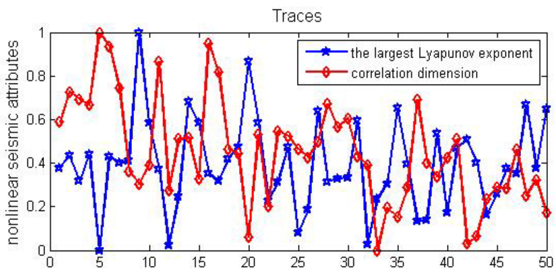


Fig. 3 *A section of seismic data* ***Fig. 4*** *The nonlinear attributes of Figure 3*

The blue line is the largest Lyapunov exponent, in the region of seismic waveform irregular, the largest Lyapunov exponent corresponds to larger value characteristics, however in regular region, and the value is smaller. The red line is the correlation dimension, in the region of seismic waveform irregular, the correlation dimension indicates smaller value characteristics. And in regular region, the value is larger. Compares with Figure 3 and 4, we can know that the largest Lyapunov exponent and correlation dimension in different regions of seismic waveform have obvious characteristics respectively. Which mean that the relationship between them is negative correlation. The region with seismic waveform weak and irregular generally corresponds to the formation of fracture and fragmentation position. To some degree, in the Ordovician limestone formation, fault and broken area often develop into water area. So we can use the largest Lyapunov exponent and correlation dimension to predict the fracture zone and then further to predict the aquosity of Ordovician limestone.

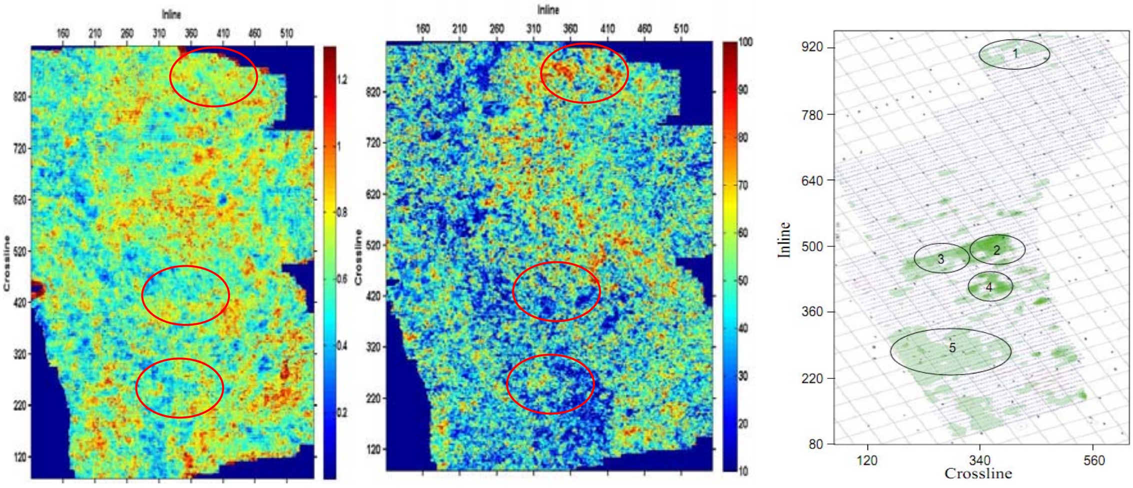
Examples of application

The characteristics of nonlinear seismic attribute

The method mentioned above is applied to actual seismic data in XT coal mine. As a result, the aquosity of Ordovician limestone has been detected. First we process seismic data using EMD, and then the largest Lyapunov exponent and correlation dimension of IMF2 data along the ordovician limestone formation are calculated. The results are shown in fig. 5(a) and (b) respectively. The area with large value of the largest Lyapunov exponent corresponds to the small value of correlation dimension.

The Result Analysis

We have performed transient electromagnetic exploration in the coal mine. Fig. 5(c) is the apparent resistivity distribution map observed by the transient electromagnetic exploration at 50-meter above the Ordovician limestone top (Huang et al. 2009). Based on the size of the apparent resistivity value, the limestone aquosity in the area is divided into four grades, i.e., strong, medium, weak, and no aquosity. Comparative analysis of the largest Lyapunov exponent, correlation dimension and the apparent resistivity, we can see that the area with larger value corresponds to the largest Lyapunov exponent and the area with smaller value corresponds to the correlation dimension. Hence it has a good corresponding relation in the apparent resistivity aquosity area. Therefore, we can use the largest Lyapunov exponent and correlation dimension of IMF2 to predict the aquosity of Ordovician limestone, and the predicted results are shown in red oval area in fig.5(a) and (b).



(a) (b) (c) （Huang et al. 2009）

Fig. 5 *(a) The largest Lyapunov exponent, (b) correlation dimension, (c) apparent resistivity*

Conclusions

From the results of Ordovician limestone aquosity prediction research based on EMD and nonlinear seismic attributes, we obtain the following conclusions:

(1) EMD can effectively decompose the seismic signal,where IMF1 corresponding to the high frequency noise of seismic signal, and IMF2 corresponding effective components of seismic signals.

(2) The largest Lyapunov exponent and correlation dimension can reflect the complexity of the formation, which can predict the fracture zone and then further predict the aquosity of Ordovician limestone.

(3) The EMD and nonlinear seismic attribute has a good application prospecting, but the endpoint effect of EMD and the physical significance of nonlinear seismic attributes need further researches.

Acknowledgements

The project was supported by the Fundamental Research Funds for the Central Universities (Grant No, 2012QNA62), the Natural Science Foundation of Jiangsu Province (Grant No, BK20130201), and Project funded by China Postdoctoral Science Foundation (Grant No, 2014M551703).

References

Battista BM, Knapp C, McGee T, Goebel V (2007) Application of the empirical mode decomposition and Hilbert-Huang transform to seismic reflection data. Geophysics 72(2): H29-H37

Bekara1 M, Baan M (2009) Random and coherent noise attenuation by empirical mode decomposition. Geophysics 74(5):V89-V98

Huang YP,Dong SH, Geng JH (2009) Ordovician limestone aquosity prediction using nonlinear seismic attributes: Case from the Xutuan coal mine. Applied Geophysics 6(4): 384-391

Huang N, Shen Z, Long SR. (1998) The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series. Proceedings of the Royal Society of London, A454:903-995

Huang YP, Geng JH, Zhong GF, Guo TL, Pu Y, Ding KY, Ma JQ (2011) Seismic attribute extraction based on HHT and its application in a marine carbonate area. Applied Geophysics 8(2): 125-133

Li Y, Peng JL, Ma HT, Lin HB (2013) Study of the influence of transition IMF on EMD do-noising and the improved algorithm. Chinese Journal of Geophysics (in Chinese) 56(2):626-634

Song HB, Bai Y, Dong CZ, Song Y (2010) A preliminary study of application of empirical mode decomposition method in understanding the features of internal waves in the northeastern South China Sea. Chinese Journal of Geophysics (in Chinese) 53(2): 393-400

Wen XT, He ZH, Huang DJ (2009) Reservoir detection based on EMD and correlation dimension. Applied Geophysics 6(1): 70-76