ON THE METHOD OF DETECTING THE DISCONTINUITY OF SEISMIC DATA VIA 3D WAVELET TRANSFORM

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1. INTRODUCTION

The consistent and reliable detection of discontinuity in 3D seismic data provides interpreters with very powerful means to quickly visualize and map complex geological structures. One of the commonly used methods for characterizing the discontinuities of seismic data is the coherence cube, such as C3 [1]. Cohen and Coifman proposed local structural entropy (LSE) [2] to reduce the expensive computations of C3. The computational cost of these methods will increase as the analyzing window widen. 1D continuous wavelet transform (CWT) has been widely used and proved to be an efficient tool to detect point singularity [3]. Since analyzing the seismic data trace by trace, it can not properly use the correlated information from neighboring traces. So one uses the 2D CWT to 2D seismic data, for instance to detect fault [4]. We notice that, when to be applied to seismic data, the 2D CWT usually fail to some weak discontinuity for the influence of amplitude. Furthermore, just as 1D CWT has some shortage to analyze the 2D data, 2D CWT has some shortage too for 3D data.

In this paper, we focus on multiscale seismic discontinuity detection through CWT. First we used 1D CWT to obtain instantaneous phase (IP) cubes for three interested scales to avoid amplitude’s affection. Then we use 3D CWT as a novel tool to detect discontinuities on these IP cubes. The results on synthetic data and field data show our method’s depicting ability of large fault and tiny discontinuities.

2. METHOD

Commonly used IP estimating method (such as Hilbert transform) is sensitive to noise, while CWT was proved to be a precisely extracting tool which has excellent antinoise performance [5]. A CWT of a real trace *f*(t) (energy limited) with respect to an mother wavelet ψ(t) is defined as a set of correlations:

$$CWT_1(s,t)=\int_{-\infty}^{+\infty} f(\tau)s^{-1/2}\psi^*\left(s^{-1}(\tau-t)\right)d\tau\ , \tag{1}$$

where t is a translation parameter and s is a scale parameter， ‘*’ represents conjugate. Given an analytical wavelet, the CWT of the signal can be written as [6]:

$$CWT_1(s,t)=\left|CWT_1(s,t)\right|P(s,t) \tag{2-1}$$

$$P(s,t)=\exp[j\phi(s,t)] \tag{2-2}$$

$\phi(s,t)$ is IP at scale s. We take $P(s,t)$ as the input of discontinuity detection to reduce the influence of amplitude and overcome the phase's jump (e.g. from 180° to -180°).

Comparing to 1D CWT, there are three kinds of basic operations on 3D mother wavelet, translation, dilation and rotation. We denote the 3D mother wavelet with $\psi(\mathbf{x})$ and the variable $\mathbf{x}$ is a vector with three elements. Then the 3D CWT is the inner product of 3D signal $f(\mathbf{x})$ and wavelet atom:

$$CWT_3(a,\mathbf{x},\theta,\varphi)=\int_{R^3} f(\mathbf{b})a^{-3/2}\psi^*\left\{a^{-3}\mathcal{R}_{\theta,\varphi}\left(\mathbf{b}-\mathbf{x}\right)\right\}d^3\mathbf{b} \tag{3}$$

the symbol $\mathcal{R}_{\theta,\varphi}$ means rotated by a dip angle θ and a azimuth angle φ. The 3D CWT's computation will not increase as the scale becoming larger, for the 3D CWT can be fast realized in spatial-frequency domain with the help of high dimensional FFT. If the 3D mother wavelet was directional wavelet (e.g. high dimensional Morlet), then the 3D CWT is a multiscale and multidirectional tool, and can be used for multiscale direction information (include dip and azimuth) extraction. We choose small scale in seismic discontinuity detection in order to obtain better spatial resolution. For a fixed scale a_{small} and fixed position $\mathbf{x}$, the discontinuities $dis(\mathbf{x})$ in a fixed position $\mathbf{x}$ in 3D cube can be measured by:

$$[\theta_{dip}(\mathbf{x}),\varphi_{azimuth}(\mathbf{x})]=\arg\min_{[\theta,\varphi]}\left|CWT_3(a_{small},\mathbf{x},\theta,\varphi)\right| \tag{4-1}$$

$$dis(\mathbf{x})=\left|CWT_3(a_{small},\mathbf{x},\theta_{dip}(\mathbf{x}),\varphi_{azimuth}(\mathbf{x}))\right| \tag{4-2}$$

This procedure can be realized through angle searching. We also noticed that the faults and other interested discontinuities in seismic cube are vertical, so the dip searching range should be restricted to [π/2-α, π/2+α] where α decide the dip searching range. The discontinuity's azimuth has no special aptness, so the searching range should be [0, 2π]. Supposing the 3D seismic cube is $F(x, y, t)$ where x and y is spatial variable and t is time variable, the complete procedure of seismic discontinuities detection based on WT is as follows:

- Confirm three interested scales [$s1$, $s2$, $s3$]. Do 1D CWT to every trace in 3D seismic cube;
- Compute IP at scales [$s1$, $s2$, $s3$], then form three cubes by formula (2-2);
- Do small scale 3D CWT to these three cubes, then use formula (4) to estimate discontinuities in these three cubes. Three discontinuities cubes were gotten;

3. EXAMPLE

A synthetic 3D seismic cube was constructed with several faults (one large fault, two x-directional small faults and two y-directional small faults) and the wavelet we use in synthetic is 30Hz ricker wavelet. The cube consists of 128 inline traces and 128 crossline traces, each containing 128 samples. A time slice (70ms) is shown in figure 1a, and a crossline (110) is shown figure1d. The corresponding time slice and crossline through C3 cube are displayed in figure1b and figure 1e, and the analyzing window in C3 is [3 3 31]. By using our method, we obtain a discontinuities cube (here we only use one interested scale). The corresponding time slice and crossline through discontinuities cube are displayed in figure1c and figure 1f. The results shows that our method not only detect large fault well but also depict small fault accurately (especially in positions where red arrows pointed).

The field data example is from Daqing oilfield. A subvolume with an inline distance of 8.000 km and a crossline distance of 13.600 km (401*681 traces) is used for demonstration. Figure 2a is a slice of 3D seismic data (flatten with marker bed). The slice of C3 and LSE (flatten with marker bed) are figure 2b and figure 2c. We focus on three scales 0.032, 0.021 and 0.016. Then we get three discontinuities cubes. The corresponding slices of these discontinuities are shown in figure 2(d-f). We find that the low frequency (large scale) based discontinuities cube depict large structure well comparing with LSE and C3, while high frequency (small scale) based discontinuities cube display tiny structure well.

4. CONCLUSION

We proposed a multiscale seismic discontinuities detecting method based on CWT. The method first does 1D CWT on 3D seismic cube to obtain several IP cubes at different scales. Then we use 3D CWT as a novel tool to detect discontinuities on these cubes. Using our method, multi-scale discontinuities cubes can be obtained. The synthetic data and real oilfield data results show that our method can depict large fault and tiny discontinuities well in different scale. These different scale discontinuities cubes can be merged to one cube which can depict seismic discontinuities entirely with the help of information fusion theory, but we did not illustrated here for limited page.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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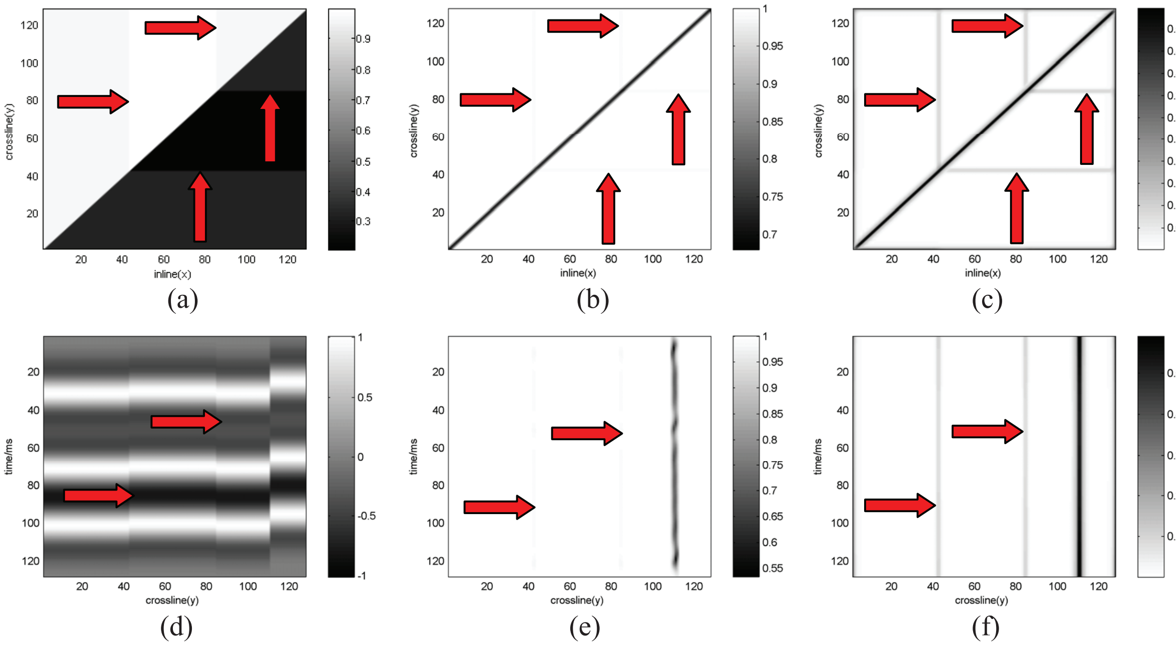
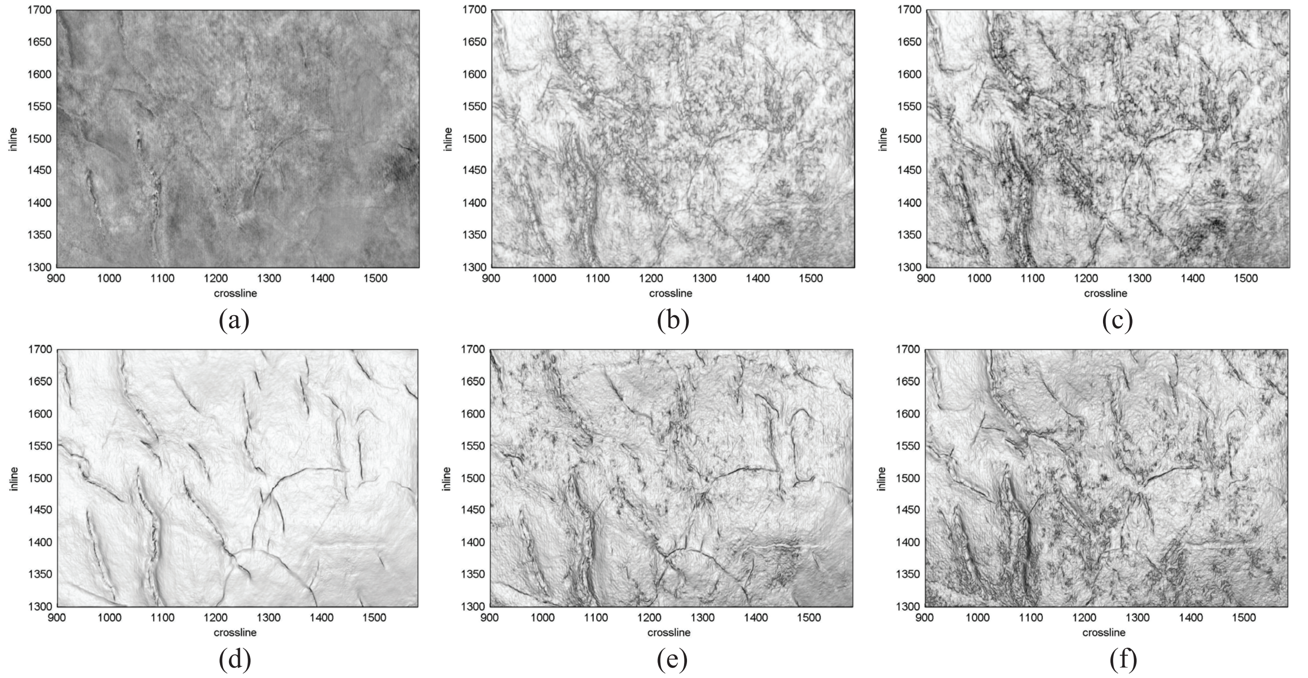


(a) (b) (c)

(d) (e) (f)

Fig.1 discontinuities detection results of synthetic data

(a)slice of synthetic data; (b)slice of C3 cube; (c) slice of discontinuities cube (our method); (d) crossline110 of synthetic signal; (e) crossline110 of C3 cube; (f) crossline110 of discontinuities cub (our method);



(a) (b) (c)

(d) (e) (f)

Fig.2 Discontinuities detection results of real oilfield data

(a)slice of 3D field data; (b)slice of LSE cube ([4 4 31]); (c)slice of C3 cube ([4 4 31]); (d)slice of large-scale discontinuities cube; (e)slice of middle-scale discontinuities cube; (f)slice of small-scale discontinuities cube;