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Time reverse locating of noise source based on isotime point imaging

Qixin Ge, Liguo Han *

Jilin University, College of Geoexploration Science and Technology, Changchun, China

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ABSTRACT

In seismic exploration, a noise source is simply described as a source producing stochastic vibration continuously. The first arrival or events of a noise source are generally unpickable. Hence it's more appropriate to use the time reverse imaging (TRI) for locating noise source rather than the travel time inversion. In this paper, we introduce TRI into the noise source locating. Hybrid imaging condition and random selection of receiver positions in back propagation are used to improve the effect and reliability of imaging result. For identifying the source, the local maxima of imaging result are extracted, combining with a statistical threshold. Besides, we propose an imaging method based on isotime point: taking imaging points as sources, and calculating the travel time around them respectively; picking several points on one or more isotime lines (which are called isotime points), and using the back propagated wavefield sequences at these points to conduct imaging. Again, a threshold is used to identify sources. Combination of results of the conventional method and that from the isotime point imaging helps eliminate artifacts. Homogenous and complex models are illustrated to verify the effectiveness of the proposed method and its resistance to white noise.

1. Introduction

Noise exploration aims at realizing exploration with reception and processing of noise data. The noise source adopted is generally characterized by natural stability, and it is simply described as a source producing stochastic vibration continuously. At present, the research on noise exploration mainly focuses on reconstruction of active record, estimation of the Green's function, and imaging of subsurface structures. Reconstruction of active record with passive record originated from the "daylight imaging" presented by Claerbout (1968), which proved that the autocorrelation of transmitted wave record from underground to ground surface is equivalent to the simulated record at ground surface of self excitation and self reception. This method is named as seismic interferometry by Schuster (2001). Cross correlation (Schuster and Rickett, 2013) is the mostly used in seismic interferometry, and it is proved to be effective in processing noise data to obtain effective information (Schuster et al., 2004; Bakulin and Calvert, 2006). The subsequent deconvolution method (Vasconcelos and Snieder, 2008a, 2008b) as well as multidimensional deconvolution method (Wapenaar et al., 2008; Wapenaar et al., 2011) respectively solved some defects of cross correlation. Structure imaging with passive data is mainly based on reconstruction of active record (Bellezza and Poletto, 2014; Zhang et al., 2015).

The existing noise source locating is mainly found in the military field, e.g. locating a submarine based on its radiated noise (Maynard et al., 1985; Veronesi and Maynard, 1987). However, the source property, medium property, detecting instrument, and locating method in the military field are much different from those in the seismic exploration. The conventional noise data processing, such as active record reconstruction, does not require the location information of noise source. Thus, there are few reports about research on noise source locating. However, taking microseismic locating (transient source) as an example, whose main application is in monitoring fracturing and displacement of underground structures; similarly, determination of the location of noise source is of great significance in monitoring of urban ambient noise, real time monitoring of groundwater migration, monitoring and warning of landslide and rock fall, monitoring and warning of active faults and active volcanoes, etc. (Xu and Luo, 2015).

The method of microseismic locating mainly contains travel time inversion (Waldhauser and Ellsworth, 2000; Poliannikov et al., 2011), and time reverse imaging (Gajewski and Tessmer, 2005; Mcmechan, 2007). The precondition of realizing the microseismic travel time inversion is to pick up the first arrival of microseismic events. Generally, the noise source has a long duration, thus it's difficult to record the first arrival in the conventional sense. Besides, its energy is dispersed along the whole duration, and coupling of events is even more serious than that of microseisms, which leads to difficulties in identifying the events.

Imaging of source location is one of the four generalized applications of seismic interferometry (Schuster, 2009). According to the characteristics of seismic interferometry, it has good adaptability to noise and can be used to locate noise source. The chain of time-reverse modeling, image domain (P—S) wavefield decomposition and applications of imaging conditions were called as TRI by Artman et al. (2010), whose basic

* Corresponding author.
E-mail address: hanliguo@jlu.edu.cn (L. Han).

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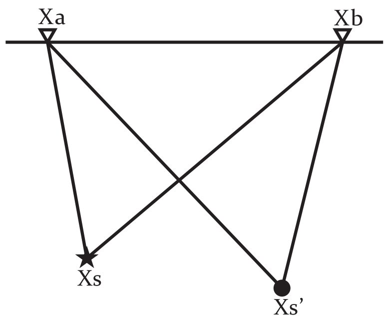

Fig. 1. A 2D model of locating imaging, with a noise source $\mathbf{x}_s$ and an arbitrary imaging point $\mathbf{x}_s'$ underground, and two receivers $\mathbf{x}_a$ and $\mathbf{x}_b$ at the surface.

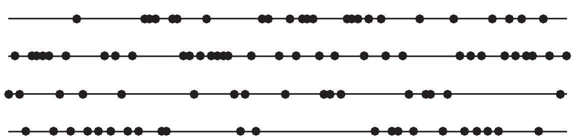

Fig. 2. A simple example of random receiver grouping at a time. 96 of total 100 receiver positions are selected and divided into 4 groups randomly; black dots on the lines denote receiver's position.

idea is consistent with seismic interferometry. As there is only back propagated wavefield in TRI, its imaging condition describes the calculation between the back propagated wavefields from the same and/or different receiver positions. The back propagated wavefields are split into scattered ones, realizing flexible application of imaging conditions, e.g. arithmetic mean imaging condition (Gajewski et al., 2007), geometric mean imaging condition (Nakata et al., 2016), and hybrid imaging condition (Sun et al., 2015), etc.

In this paper, we illustrate the feasibility of TRI with noise source locating in terms of seismic interferometry. Then, we use hybrid imaging condition and random selection of back propagation receiver positions (Ge et al., 2017) to enhance the preliminary TRI result. Next, we propose an imaging method based on isotime point: calculating the travel time with an imaging point as a source, utilizing the back propagated wavefields at its isotime points to conduct imaging. The origin of impact in this imaging method is a little different from that in conventional method. By combining the two results together, the artifacts are eliminated effectively. Finally, feasibility of the proposed method to locate noise source and the resistance to white noise are verified with 2D acoustic model.

2. Principle and method

2.1. Seismic interferometry and noise source locating

This section focuses on the characteristics of 1D seismic interferometry and the feasibility of locating 2D noise source with TRI.

In a 1D medium, the Green's functions of three points in time-domain satisfy the following relation:

$$\mathrm{G}(\mathbf{x}_b, \mathbf{x}_a, \mathrm{t}) = \mathrm{G}(\mathbf{x}_b, \mathbf{x}_a, \mathrm{t}) * \mathrm{G}(\mathbf{x}_a, \mathbf{x}_s, -\mathrm{t}) \tag{1}$$

where, $\mathbf{x}_a$ and $\mathbf{x}_b$ represent the receiver positions; $\mathbf{x}_s$ represents the source position and must be located at the side of $\mathbf{x}_a$, otherwise the left side of the equation becomes an acausal component; t is the delay time; the asterisk * denotes convolution; $\mathrm{G}(\mathbf{r},\mathbf{s},\mathrm{t})$ represents the impulse response stimulated by **s** and received by **r**, i.e. the Green's function from **s** to **r**. The "-" in front of *t* in the second term of the right side represents reversing time axis. Considering convolution needs to reverse the sequence again, the right side actually represents the cross correlation of the two Green's function. This equation is still valid in the case of a 2D medium, and the premise is similar: $\mathbf{x}_s$, $\mathbf{x}_a$ and $\mathbf{x}_b$ must occur in a same wave path in proper order.

The records $\mathrm{u}(\mathbf{x}_a,\mathbf{x}_s,\mathrm{t})$ and $\mathrm{u}(\mathbf{x}_b,\mathbf{x}_s,\mathrm{t})$ at the two receiver positions are expressed as $\mathrm{G}(\mathbf{x}_a,\mathbf{x}_s,\mathrm{t}) * s(t)$, and $\mathrm{G}(\mathbf{x}_b,\mathbf{x}_s,\mathrm{t}) * s(t)$ respectively. Hence, Eq. (1) shall be modified as

$$\mathrm{G}(\mathbf{x}_b, \mathbf{x}_a, \mathrm{t}) * S(t) = u(\mathbf{x}_b, \mathbf{x}_s, \mathrm{t}) * u(\mathbf{x}_a, \mathbf{x}_s, -\mathrm{t}) \tag{2}$$

where u is the convolution of G and the source wavelet $s(t)$, i.e. the seismic record; $S(t)$ is the auto correlation of $s(t)$. $s(t)$ has an arbitrary type and can be set as noise. This equation indicates that

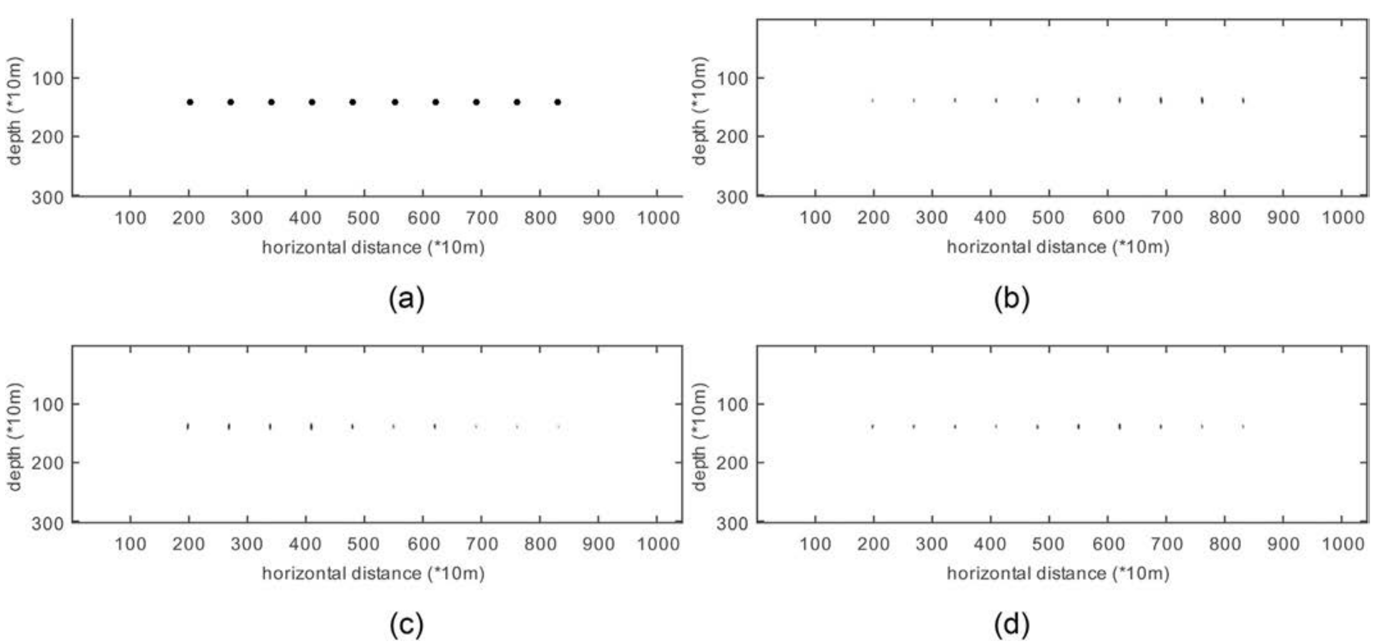

Fig. 3. (a) Model and distribution of noise sources points; (b)(c)(d) Three imaging results obtained with same data and different random groups. The darker color indicates the greater the imaging value. Each result has its own emphasis.