Seismic Wavelet Signal Noise Reduction Algorithm of Blind Source Separation Optimization

Qiao Wang

College of Earth Science, Jilin University,
Changchun 130061, Liaoning, China

Yue Liu

Institute of Information Engineering, Kaifeng University,
Kaifeng 475004 Henan, China

Abstract
In view of the existing seismic signal analysis model there are some problems is Analysis of the result is bad, the accuracy is not high. This paper puts forward an algorithm based on discrete wavelet and generalized the ICA model of seismic signal analysis. First for continuous Wavelet transform exists redundant of problem, on standard small wave transform algorithm of transform domain in the variable for discrete of, and building based on discrete optimization Wavelet algorithm of earthquake signal drop noise model, then in used Discrete Wavelet transform algorithm on signal for drop noise Hou, used ICA algorithm on its for blind separation optimization, and introduced general Gaussian distribution model, on ICA algorithm for Diego generation operation of optimization. Simulation experiments show that presented Discrete Wavelet transform algorithm relative to the standard Wavelet has better noise reduction ability, and is based on discrete wavelets and generalized seismic signal analysis of ICA algorithm model shows good results.
Key words: SEISMIC EXPLORATION, SIGNAL ANALYSIS, SIGNAL NOISE REDUCTION, BLIND SOURCE SEPARATION, THE WAVELET TRANSFORM

Introduction

In geophysical prospecting technology in the development process, demand has been for exploration and development of petroleum geophysical exploration technology driving force. Gradually into maturity with the petroleum industry, exploration of increasing difficulty, geophysical work has shifted from simple to complex surface and underground areas, seismic data rate, resolution and structural precision put forward higher requirements [1]. And in improve production, and reduced cost of double pressure Xia, development production on geophysical work also proposed has urgent of requirements geophysical workers to development of scale provides more high of storage layer situation, on reservoir for dynamic monitoring, maximum to improve harvest than, this not only for geophysical technology of development injected has new of vitality, also makes earthquake data of application value get has great improve [2].

In seismic exploration, field data collection is wide-band digital seismograph records. So, while records from the subsurface wave also recorded from above and below ground interference regardless of the formation of the various waves. Divided into rules of interference wave interference, and random interference waves two categories [3]. Interference wave refers to the rules, fat, thin, and transmission speed, and there are certain rules, as of surface wave propagation along the ground, car speakers, when the train whistle sound, high-voltage induction wave. Irregular noise also known as random noise, it is some random vibrations, such as trouble on the ground, walking, car dealers and vibration caused by underground between broken formation and so on. Corresponds to the different characteristics of noise and denoising method puts. Due to noise rules generally have simple spatial characteristics, by filtering, filtering, Radon transform or Beamforming removal [4]. It is difficult to directly remove random noise in the time domain, but has obvious characteristics, such as noise or low noise, high frequency 50Hz interference, you can filter in the frequency domain to remove. The Fourier transform is widely used in seismic signal Denoise, Fourier transform is the theory of signal analysis and processing based denoising method based on Fourier transform include filtering in the frequency domain method and frequency-wavenumber domain filtering methods [5]. Can signal Wavelet transform on the multiscale Wavelet Decomposition, decomposition of wavelet transform coefficients on different scales of the original signal information in different resolution [6]. Because the signal and Wavelet Decomposition of random noise on a different scale, different characteristics, which are important for signal analysis, many scholars use the characteristics of signal denoising and achieved good results. Witkin by using Wavelet Decomposition of signals at different scales of space-related noise in [7]. Mallat said, by finding local maxima of the wavelet transform coefficients based on signal reconstruction, prior to the noise can be a good approximation of the original signal [8]. Donohot presents a Wavelet-domain denoising method based on threshold, threshold value based on wavelet transform coefficients and the retention signals of wavelet coefficients reconstruction [9]. The different frequency components of the signal to noise ratio of seismic data is different, and different frequency components of the signal to noise ratio improved to improve the overall resolution of the signal is different, high frequency signal to noise ratio of seismic signals generally low and high frequency information is significant for reflecting the seismic response of thin sand bodies [10].

In this paper, the existing problems of seismic signal analysis model is proposed based on discrete wavelets and generalized seismic signal analysis of ICA algorithm model and its simulation, verify the validity of the model.

Seismic signal based on wavelet noise reduction

Algorithm of continuous Wavelet transform

Wavelet analysis is a new branch of mathematics developed in recent years, has now become a very active area of research at the international level, it has been widely used in image processing, speech synthesis, seismic exploration, atmospheric turbulence, and other fields. Its basic properties are as follows:

Set the continuous Wavelet transform (sometimes referred to as the integral Wavelet transform) is defined as:

$$WT_f(a,b) = |a|^{-1/2}\int_{-\infty}^{\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt, a \neq 0 \quad (1)$$

Or inner product forms:

$$WT_f(a,b) = \left\langle f, \psi_{a,b}\right\rangle \quad (2)$$

Type:

$$\psi_{a,b}(t) = |a|^{-1/2}\ \psi\left(\frac{t-b}{a}\right) \quad (3)$$

To make the inverse transform, allows conditions to be met:

$$C_\psi = \int_{-\infty}^{\infty}\frac{|\hat{\psi}(\omega)|^2}{|\omega|}d\omega < \infty \quad (4)$$

Type in the Fourier transform.

At this point, the inverse transformation

$$f(t) = C_\psi^{-1}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\psi_{a,b}(t)WT_f(a,b)db\frac{da}{|a|^2} \quad (5)$$

This constant limits as "basic Wavelet (or mother Wavelet)" belongs to the class of functions, especially if the requirement is a Windows function, it must also belong to, that is

$$\int_{-\infty}^{\infty}|\psi(t)|\,dt < \infty \quad (6)$$

It is a continuous function. By equation (4) can be at the origin is zero, that is,

$$\hat{\psi}(0) = \int_{-\infty}^{\infty}\psi(t)dt = 0 \quad (7)$$

By(6) you can see that the wave function must have oscillation. Continuous Wavelet transform has the following properties

(1) let $f(t) = \alpha g(t) + \beta h(t)$, while

$$WT_f(a,b) = \alpha WT_g(a,b) + \beta WT_h(a,b) \quad (8)$$

(2) if $f(t) \Leftrightarrow WT_f(a,b)$, while

$$f(t-\tau) \Leftrightarrow WT_f(a,b-\tau) \quad (9)$$

Translation invariance is a very good property, in practice, although Discrete Wavelet transform is widely used, but in the case of need for translation invariance, the discrete Wavelet transform is not used directly.

(3) if $f(t) \Leftrightarrow WT_f(a,b)$, while

$f(ct) \Leftrightarrow \frac{1}{\sqrt{c}} WT_f(ca,cb)$, whice $c > 0$ 。

(4) Continuous wavelet transform in redundancy of information expression. Its performance by continuous wavelet transform to restore the original signal reconstruction formula is not the only, the wavelet transform of kernel function is there are many possible choices. Despite the presence of redundancy can improve the signal stability of the calculation, but increased analysis and explain the difficulty of the results of wavelet transform

Based on the discrete optimal wavelet algorithm of seismic signal noise reduction

Because of the continuous Wavelet transform is redundant, it is necessary to figure out, in order to reconstruct the signal required for transform domain variable, discretization to eliminate redundancy in transformation, in practice, often, and; When

$$\psi_{a,b}(t) = \psi_{\frac{1}{2^j},\frac{k}{2^j}}(t) = 2^{j/2}\psi(2^j t - k) \quad (10)$$

Often abbreviated to:

$\psi_{j,k}(t)$

Transformation in the form of：

$$WT_f\left(\frac{1}{2^j},\frac{k}{2^j}\right) = \left\langle f, \psi_{j,k} \right\rangle$$

In order to reconstruct the signal, which requires is Riesz base.

A function is called a function, if is a Riesz basis in the following sense: linear Zhang is dense, and there is a normal number, so

$$A \| \{c_{j,k}\} \|_{l^2}^2 \le \| \sum_{j\in-\infty}^{\infty} \sum_{k\in-\infty}^{\infty} c_{j,k}\psi_{j,k} \|_2^2 \le B \| \{c_{j,k}\} \|_{l^2}^2 \quad (11)$$

All double doubly infinite sequence of square and set up, that is set up.

Assumed to be a function, then there exists a unique Riesz basis, and its significance

$$\left\langle \psi_{j,k}, \psi^{l,m} \right\rangle = \delta_{j,l}\delta_{k,m},\ j,k,l,m \in Z \quad (12)$$

With the dual. At this time, each type (7) unique series representation

$$f(t) = \sum_{j=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} \left\langle f, \psi_{j,k} \right\rangle \psi^{j,k}(t) \quad (13)$$

In particular, when consisting of orthogonal basis, there is reconstruction formula is:

$$f(t) = \sum_{j=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} \left\langle f, \psi_{j,k} \right\rangle \psi_{j,k}(t) \quad (14)$$

Seismic signal denoising based on wavelet algorithm for discrete optimization process is as follows:

(1) Discrete Wavelet transform on noisy seismic signals, usually larger, so that the signal of modulus maximum number of points to the advantage, but if the scale is too large, you will lose some important signals of singular characteristics. Usually choose the scale for 4-5;

(2) Search on each scale modulus maxima of wavelet transform coefficients;

(3) Starting from the largest scale, choose a threshold value, if the absolute value of the maximum amplitude is smaller than, the extreme point is discarded or retained, depending on the maximum scale of the new Maxima. General threshold is as follows

$$A = \frac{\log_2(1+2\sqrt{N})}{J+Z} \quad (15)$$

As a preset in the noise power, the maximum scale for selected, is a constant, usually.

(4) In the scale for the maxima constructs a neighborhood where, retained within the neighborhood of modulus maximum points, removal fell on adjacent Maxima points outside, then repeat until;

(5) Retained in the time of modulus maximum points corresponding to Maxima, the coefficient on the remaining position reset to zero;

(6) Reservations on each scale modulus maxima of wavelet coefficients reconstruction points, and then reconstruction of the wavelet coefficients for signal recovery.

Optimization of seismic signal blind separation

In order to better analyze seismic signals, an accurate source, based on the discrete Wavelet transform algorithm for signal noise reduction, using ICA algorithm for blind separation of optimization.

Uncertainty analysis of independent component analysis algorithm

Independent component analysis (ICA) algorithm is based on the basic principle of independent measurement principle to set up a function through the solution after the separation of the functions of each component as close as possible the source signal.

First of all, a probability density function can be expressed as:

$$q(Y) = \prod_{i=1}^{N} f(Y_i) \quad (16)$$

Yes first component on the marginal probability density function, which can be expressed as:

$$f(Y_i) = \int_{-\infty}^{+\infty} f_y(Y)\tilde{Y}^i \quad (17)$$

(17)the component does not contain that is integral. In this algorithm, algorithmic entropy between the cost function is selected and, probability density function of two differences is smaller, the entropy values closer to 0. The definition of entropy is as follows:

$$D_{fq} = D_{fq}(f_y(Y)\,\|\,q(Y)) = \int_{-\infty}^{+\infty} f_y(Y)\log\frac{f_y(Y)}{q(Y)}dY$$
$$= \int_{-\infty}^{+\infty} f_y(Y)\log\frac{f_y(Y)}{\prod_{i=1}^{N} f(Y_i)}dY \quad (18)$$
$$= \int_{-\infty}^{+\infty} f_y(Y)\log f_y(Y)dY - \sum_{i=1}^{N}\int_{-\infty}^{+\infty} f_y(Y)\log f(Y_i)dY$$

Due to

$$\int_{-\infty}^{+\infty} f_y(Y)\log f(Y_i)dY = \int_{-\infty}^{+\infty}\log f(Y_i)\int_{-\infty}^{+\infty}\log f_Y(Y)d\tilde{Y}^i dY_i$$
$$= \int_{-\infty}^{+\infty} f(Y_i)\log f(Y_i)dY_i = E\{\log(f(Y_i))\} \quad (19)$$
$$= -H(Y_i)$$

(18) can be expressed as:

$$D_{fq} = -H(Y_i) + \sum_{i=1}^{N} H(Y_i) \quad (20)$$

By $Y(t) = WX(t)$ available：

$$H(Y) = H(X) + \log|\det(W)| \quad (21)$$

(21)and matrix of discrete, (20) can be transformed into:

$$D_{fq} = -H(X) - \log|\det(W)| - \sum_{i=1}^{N} E\{\log(f(Y_i))\} \quad (22)$$

(22) in the equation on calculating the partial derivatives on both sides and replace the expectations with the instantaneous value can be obtained:

$$\frac{\partial D_{fq}}{\partial W} = -W^{-T} + \varphi(Y)X^T \quad (23)$$

(23), ICA algorithm for blind source separation in the event function, as follows:

$$\varphi_i(Y_i) = -\frac{d\log f_i(Y_i)}{dY_i} = \frac{f_i'(Y_i)}{f_i(Y_i)} \quad (24)$$

(24) on either side of the times can be obtained, respectively:

$$\Delta W = -\frac{\partial D_{fq}}{\partial W}W^T W = [I - \varphi(Y)Y^T]W \quad (25)$$

Finally the expression of blind source separation algorithm:

$$W(k+1) = W(k) + \eta(k)(I - \varphi(Y(k))Y^T(k))W(k) \quad (26)$$

(26) the learning rate

As can be seen from the above steps, of which the ICA face and order of ICA is the uncertainty inherent to the problem. And seismic signal amplitude on the amount of contribution is very big, so first of all ICA algorithm was optimized.

Analysis of seismic signals based on ICA algorithm model

For ICA algorithm, or there is insufficient separation problem, this paper presents generalized Gaussian distribution model, the original algorithm is an iterative optimization.

Generalized Gaussian distribution probability density function is as follows:

$$p(y,a) = \frac{a}{2\sigma\Gamma(\frac{1}{a})}e^{-\left|\frac{y}{\sigma}\right|^a} \quad (27)$$

Type（27）medium,

$$\Gamma(x) = \int_0^{\infty} t^{x-1}e^{-t}dt \quad (28)$$

Moment estimation of generalized Gaussian distribution formula is as follows:

$$M_n = \int_{-\infty}^{+\infty} y^n p(y,a)dy \quad (29)$$

Due to the generalized Gaussian distribution probability density function is an even function, then was in the odd moments of generalized Gaussian distribution function is an odd function, so zero in the interval of integration, which means that generalized Gaussian distribution the odd moments are zero. To compute the generalized Gaussian distribution of even-order moments:

$$M_2 = \int_{-\infty}^{+\infty} y^2 p(y,a)dy = 2\int_{-\infty}^{+\infty} y^2\frac{a}{2\sigma\Gamma(\frac{1}{a})}e^{-(\frac{y}{a})^a}dy$$
$$= \frac{a}{2\sigma\Gamma(\frac{1}{a})}\int_{-\infty}^{+\infty} y^2 e^{-(\frac{y}{a})^a}dy \quad (30)$$

hypothesis $z = \frac{y}{\sigma}$, while $dy = \sigma dz$, then：

$$M_2 = \frac{a\sigma^2}{\Gamma(\frac{1}{a})}\int_0^{+\infty} z^2 e^{-x^a}dz \quad (31)$$

And there was：

$$\int_0^{+\infty} y^{\nu-1}e^{-\mu y^a}dy = \frac{1}{a}\mu^{-(\frac{1}{\nu})}\Gamma(\frac{\nu}{a}) \quad (32)$$

The vertical (31) and (32) available:

$$M_2 = \sigma^2\frac{\Gamma(\frac{3}{a})}{\Gamma(\frac{1}{a})} \quad (33)$$

The same available:

$$M_4 = \sigma^4\frac{\Gamma(\frac{5}{a})}{\Gamma(\frac{1}{a})} \quad (34)$$

Thus even-order moment estimation for generalized Gaussian distribution:

$$M_{2k} = \sigma^{2k}\frac{\Gamma(\frac{2k+1}{a})}{\Gamma(\frac{1}{a})} \quad (35)$$

By the even-order moments of generalized Gaussian distribution, we can get the kurtosis of the generalized Gaussian distribution:

$$k(y) = \frac{M_4}{(M_2)^2} - 3 \quad (36)$$

Gaussian exponential representation of

kurtosis:

$$k_a = \frac{\Gamma(\frac{5}{a})\Gamma(\frac{1}{a})}{\Gamma^2(\frac{3}{a})} - 3 \qquad (37)$$

In summary, active function that can be modified ICA algorithms for:

$$\varphi_i(y_i) = a\,|\,y_i\,|^{a-1}\, sign(y_i) \qquad (38)$$

Improve the ICA's core is calculated to recover after each iteration of each source of peak value to change the value, used in the next iteration. So for the seismic signal blind separation of noisy, first using the wavelet algorithm for discrete optimization of mixed-signal in the midst of noise and blind source separation. Algorithm is shown in Figure 1:

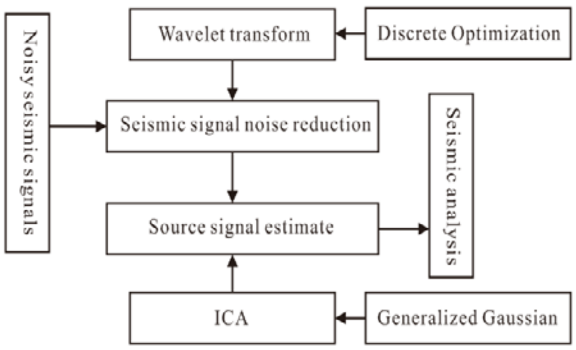

Figure 1. Seismic signal analysis process

Algorithm performance simulation

In order to verify the improved algorithm performance, first on the discrete Wavelet transform for denoising algorithm performance simulation, results are as follows.

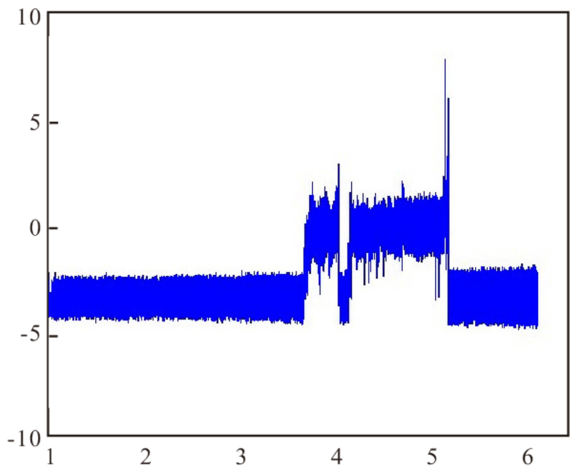

Figure 2. Noisy seismic signals

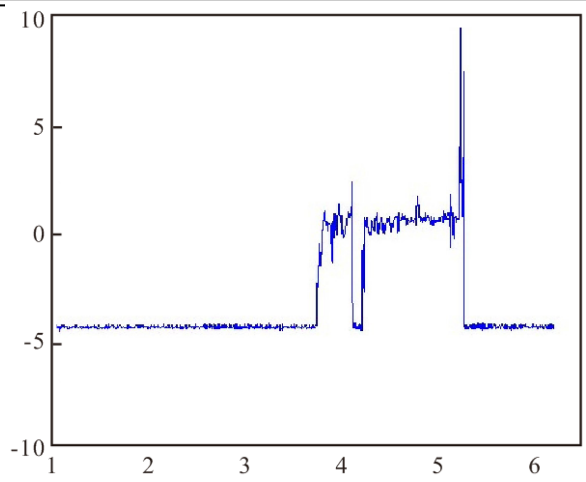

Figure 3. Discrete wavelet denoising results

Finally, proposed using 10 noisy seismic signal based on discrete wavelets and generalized seismic signal analysis model of ICA algorithm performance simulation tests are carried out, the results shown in the following figure.

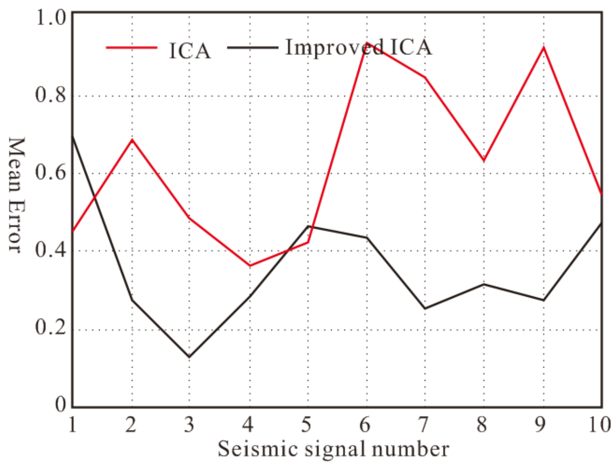

Figure 4. Comparative analysis of the accuracy of seismic signals

As can be seen from the above results, presented the discrete Wavelet transform algorithm relative to the standard Wavelet has better noise reduction ability, and is based on discrete wavelets and generalized seismic signal analysis of ICA algorithm model shows good results.

Conclusion

Seismic exploration in oil and coal exploration is an important geophysical methods. It is an artificially generated earthquake wave, based on the elastic rock, study the laws of propagation of seismic wave in the stratum, to identify subsurface geologic structure of the method. Seismic exploration in the field seismic data collected when accompanied by a lot of noise, need to digital processing, extracting useful information, so as to provide reliable information for geological interpretation of seismic exploration. Presented in this paper are based on discrete wavelets and generalized seismic signal analysis of ICA algorithm model simulation results show that the proposed improvement program to be effective, greatly improves the accuracy of seismic signal analysis

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