Seismic exploration device based on time-frequency space algorithm

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Abstract. Among the exploration methods of oil and gas resources, one of the most important exploration methods is seismic exploration. Due to economic development, the previous shallow exploration has been unable to meet the needs, and it is necessary to conduct exploration in deep geological layers. However, as the depth increases, the signal of the geophone gradually weakens and the noise interference increases, which makes the denoising work of seismic exploration more important. Aiming at the above problems, this paper proposes the research of seismic exploration equipment based on time-frequency space algorithm, and uses different window lengths for processing based on the time-frequency peak filtering algorithm. Through simulation experiments on seismic exploration data with different frequencies, the results show that the method proposed in this paper improves the effective signal amplitude maintenance by more than 11%, and the amplitude maintenance is higher than 88%. The signal-to-noise ratio also improved from -8dB before filtering to 12.13dB. This shows that the method proposed in this paper can better meet the needs of seismic exploration signal processing.

1. Introduction
The country's economy is developing rapidly, and economic development is inseparable from energy support [1]. The demand for oil and gas energy in social production and life has increased significantly, and the resources that are easy to collect are also becoming less and less. This requires further exploration of fossil energy [2]. Seismic exploration is an effective method for fossil energy exploration. The artificially excited earthquakes obtained by explosive explosions or artificial impacts analyze the propagation of elastic waves in all directions [3]. This is extremely important for solving complex oil and gas reservoirs and unconventional reservoir exploration and development. In the field of seismic exploration, many experts and scholars have conducted research and achieved fruitful results. In [4], the author determined the noise source function for earthquake random noise based on wind vibration theory and preliminary research on environmental vibration. By solving the non-uniform wave equation, various noise waveforms are obtained, and the noise suppression effect is achieved. In [5], the authors used land streamers and drop hammers to develop cost-effective seismic mineral exploration methods. In 4 days, approximately 3.5 km of seismic data was obtained using a source and receiver spacing of 2–10 m. In [6], the authors solved the problem of sparse multi-channel seismic deconvolution. By introducing multi-channel sparse peak inversion as an iterative process, deconvolution of the seismic data and restoration of the two-dimensional reflectivity image of the earth are taken into account, while considering the relationship between spatially adjacent traces. In [7], the author provided an effective method for representing the physical wave field through drumbeat-beamlet transform, and obtained an estimate of the real signal from the observed noise data. Although the above studies have achieved certain results, there are still some shortcomings. For example, the noise suppression effect is not strong,
the signal interference problem still exists, and the processing of complex signals is slightly insufficient. The inter-channel correlation of the same phase is not fully considered.

The time-frequency-space algorithm works in the space-time domain and uses the time-frequency peaks to remove noise. This method is applied in many fields. In [8], the author applied this method to monophonic speech separation in reverberation and noisy environments, which improved the objective perception quality and intelligibility of speech. In [9], the author applied this method to GPS positioning, which eased the mixing of direct signals from satellites and signals reflected from objects near the antenna, and effectively improved the positioning accuracy. In [10], the author used this method to diagnose the rolling bearing faults. By extracting the characteristic parameters of faults and identifying the faults of rolling bearings, the good running condition of the rotating machinery was guaranteed. In summary, the time-frequency-space algorithm has obvious advantages in processing noise signals, etc. It is considered to use this method in seismic exploration equipment to study the random noise suppression of seismic exploration.

Aiming at the problems of weak effective signals and strong interference in deep seismic exploration, this paper proposes the research of seismic exploration equipment based on time-frequency space algorithm. Through the improvement of the time-frequency peak filtering algorithm, a variable-length window is used for processing, in order to provide a reference for related seismic exploration in suppressing noise.

2. Method

2.1 Overview of seismic exploration
Seismic exploration is a geophysical exploration method. It uses the elasticity and density difference of the underground medium caused by artificial excitation to observe and analyze the propagation law of seismic waves generated by underground artificial earthquakes, and infers the nature and shape of underground rocks. Seismic exploration is the most important method in geophysical exploration, and it is also the most effective method to solve oil and gas exploration problems. This is an important means of surveying oil and gas resources before drilling. It is also widely used in coalfield and engineering geological surveys, regional geological research and crustal research. As the seismic wave expands downward, the direction of the seismic wave will change when different rock formations pass, and then it will be received by the detector on the ground. After this, the geomorphology and properties of the subsurface rock formations were further speculated through the record of the geophone.

2.2 Time-frequency peak filtering algorithm
Time-frequency peak filtering (TFPF) algorithm is a very effective low-SNR noise reduction algorithm for noisy signals. This algorithm uses the instantaneous frequency of the analysis signal PWVD of the noise signal as an estimate of the effective signal to complete the denoising.

Noise signals can be modeled by:

\[ s(t) = x(t) + v(t) \] (1)

In the above formula, \( s(t) \) is the observed value, \( x(t) \) is the effective signal, and \( v(t) \) is the noise interference.

First, the modulation frequency. The observed value \( s(t) \) is coded to obtain the instantaneous frequency of the analytical signal \( z(t) \). The formula is as follows:

\[ z(t) = e^{-j2\pi \mu \int s(\lambda) d\lambda} \] (2)

In the above equation, \( \mu \) is the scaling factor for the \( z(t) \) phase.

Second, calculate the PWVD of the analytical signal. The calculation formula is as follows:

\[ W_{\rho_c}(t, f) = \int_{-\infty}^{\infty} w(\tau)z(t + \frac{\tau}{2})z^*(t - \frac{\tau}{2})e^{-j2\pi f\tau} d\tau \] (3)
Third, the instantaneous frequency at the peak in PWVD is used as an estimate of the effective signal $x(t)$, and the calculation formula is as follows:

$$\hat{x}(t) = \frac{\arg \max_{W_f, \mu}[W_{pc}(t, f)]}{\mu}$$  \hspace{1cm} (4)

### 2.3 Noise suppression in seismic exploration based on time-frequency space algorithm

The fixed window length cannot achieve the best results of signal recovery and noise suppression at the same time. A smaller window length is more effective in signal recovery, while a larger window length can better suppress noise. Therefore, it is improved on the basis of the time-frequency peak filtering algorithm.

Select the window length and set the delay time to meet the continuity of the time domain. Construct a delay vector for a noisy sequence $\{s_i\}$. In the reconstructed phase space, the Euclidean distance between every two delay vectors is:

$$d = \|s(i) - s(j)\| (i \neq j)$$  \hspace{1cm} (5)

After the delay vector set is defined, the variance of the noisy sequence is regularized to obtain the vector variance. Similarly, the delay vector variance is obtained. Time-varying window length processing can use smaller window lengths to retain more valid signals in the crest portion of valid signals, use larger window lengths to suppress noise as much as possible, and use window lengths of intermediate length to perform smooth. Therefore, both the requirements for signal recovery and noise suppression are considered, and the two-way sacrifice caused by the fixed window length to be weighted is reduced.

### 3. Experiment

In order to verify the effectiveness of the method proposed in this paper, this paper conducts analysis through synthetic seismic survey records. In the experiment, the 40-channel synthetic seismic record includes two in-phase axes: the propagation velocity of the coincident axis with the main frequency of 40Hz is 1900m/s, and the propagation velocity of the coincident axis with the main frequency of 25Hz is 2600m/s, and the recording time is 1.32s, sampling frequency is 1000Hz, track interval is 30m. Then add Gaussian white noise to make the signal-to-noise ratio -8dB. Then select different window length values, analyze the relationship between the selection of window length and noise suppression, and conduct in-depth analysis.

### 4. Results

Result 1: Number of mark results

In the graph of the amplitude of the waveform over time, it can be divided into a signal part, a noise part, and a peak part according to the waveform change. In order to specifically determine which part the recording point belongs to, the number of markings is introduced in the experiment, and the recording point whose marking number exceeds 0.99N (N is the measurement length) is determined as the peak portion; the recording point whose marking number is between 0.75N ~ 0.99N is determined as Signal part; if the number of marks is less than 0.75N, it is judged as noise part. The change of the number of marks in the experiment with time is shown in Figure 1.
From the number of marks in Figure 1, it can be obtained that from time to time, the waveform is from the left to the right in the noise part, signal part, crest part, signal part, noise part, signal part, crest part, signal part, noise part. By determining the waveform of each period, it is convenient for subsequent operations.

**Result 2: comparison of filtering results**

In order to verify the effectiveness of the method proposed in this paper, the 12th seismic survey record was selected for Fourier transformation, and the traditional time-frequency peak filtering algorithm and the time-frequency space algorithm proposed in this paper were used to filter the 40Hz and 20Hz records, respectively. The filtering results are shown in Table 1.

|                      | 40Hz signal amplitude maintenance | 25Hz signal amplitude maintenance | Signal to noise ratio |
|----------------------|----------------------------------|----------------------------------|-----------------------|
| Before filtering     | 100%                             | 100%                             | -8dB                  |
| Time-frequency peak filtering algorithm | 70.13%                           | 78.22%                           | 1.06dB                |
| Time-frequency space algorithm in this paper | 91.87%                           | 89.25%                           | 12.13dB               |

As can be seen from Table 1, the seismic noise suppression method based on the time-frequency space algorithm proposed in this paper has improved the effective signal amplitude maintenance by more than 11% in the processing of records of different frequencies, and the degree of amplitude maintenance is higher than 88%, such results show that the method proposed in this paper can better meet the needs of seismic exploration signal processing. In addition, the signal-to-noise ratio has also increased from -8dB before filtering to 12.13dB, which is more obvious. Noise suppression is the most concerned issue of seismic exploration equipment. If the noise is not eliminated properly, it will seriously affect the final exploration results and even allow users to make wrong judgments, which will eventually lead to serious economic losses.

**5. Conclusions**

In the exploration of oil and gas resources, due to the complexity of the geological environment and the existence of a lot of noise, it brings serious interference to the exploration of oil and gas resources. Aiming at the problems of unstable signal and low signal-to-noise ratio in seismic survey, this paper
proposes a seismic survey method based on time-frequency space algorithm to suppress random noise and improves the shortcomings of traditional time-frequency peak filtering algorithms. The ground meets the requirements of high signal-to-noise ratio, high resolution and high fidelity. The method proposed in this paper can better recover the effective signal in the low signal-to-noise ratio environment, and has more advantages in processing weak and complex effective signals.

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