RECOVERY OF SEISMIC EVENTS BY TIME-FREQUENCY PEAK FILTERING

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ABSTRACT

The time-frequency peak filtering (TFPF) technology is applied for recovering seismic events without loss of valid information. By using frequency modulation signal encoding and taking peak of Wigner-Ville distribution (WVD) of encoded analytic signal, valid reflect signals constructing seismic events are estimated. To reduce the deterministic bias of TFPF resulted from nonlinearity of seismic reflect signal, the pseudo WVD (PWVD) TFPF is utilized. The reduced bias window length is derived by analyzing bias from experimental resulting. Testing of this method on synthetic seismic data and common shot point recordings indicates that TFPF technique significantly enhances signals from noisy seismic data and improves the continuity of seismic events by filtering out most of the additive noise. The resulting shows the clean recovery of seismic events in noise level down to a signal-to-noise ratio of -2.4dB.

***Index Terms*—** Time-frequency peak filtering, seismic events, signal enhancement, random noise, common shot point

1. INTRODUCTION

The information contained in seismic events of seismic data plays a fundamental role in the study of underground geological structures. Distortion of seismic events would degrade the quality of imaging and interpreting underground geological structure. Recovery of events depends on high SNR raw seismic data and correlation of corresponding reflect signal in multichannel recordings.

Random noise resulted from random oscillation during acquiring seismic data exists in seismic data over entire time and frequency. So it is difficult to remove random noise from the noisy seismic data of which signal-to-noise ratio (SNR) is less than 0.5dB. Strong noise makes identification of seismic events difficult.

Many efforts have been made to remove random noise in seismic data by seismologists to make seismic events legible. De-noise technologies in seismic data are performed using standard techniques, developed mainly in the framework of reflection seismics, in order to treat single-trace or multichannel data. In particular, seismic data of sufficiently good quality do not require any more complex procedures than simple single–trace frequency filters or zero-phase wavelet deconvolution[1]. Some technologies, such as *f-x* filtering, polynomial fitting, singular value decomposition and median filter etc., often are useful to suppress the random noise in application of seismic exploration [2-4]. But they can’t provide good performance under the condition of low SNR, lapping frequency spectrum or poor stability respectively.

Time-frequency peak filtering is a signal enhancement method, which is two-step procedure including signal encoding by frequency modulation and instantaneous frequency (IF) estimation by taking the peak of time-frequency representation of encoded signal [5,6]. The object of the first step is transforming signal into the instantaneous frequency (IF) of encoded signal, called analytic signal. Considered bandlimited deterministic signal, significant energy concentration is produced around the IF on the time-frequency plane of analytic signal, given IF is linear function of time. The TFPF method used to estimate IF is by taking the peak of WVD of analytic signal because of its simplicity for implementation. The peak of WVD is the unbiased estimation of desired signal.

The recovery of seismic event based on TFPF is presented here, which utilizes the signal enhancement capability of TFPF. Section 2 discusses the principle of TFPF for processing seismic recordings. The equation for reduced bias window length for seismic data is also derived. Finally, the testing is made on synthetic seismic data and common shot point data respectively in section 3. The resulting shows a good performance in recovery of seismic events in filtered data.

2. TFPF IN SEISMIC DATA PROCESSING

2.1. TFPF for Seismic Data Filtering

A trace of seismic data can be modeled as following.

$$s(t)=x(t)+n(t) \tag{1}$$

where $x(t)$ is a seismic reflect signal which is bandlimited deterministic nonstationary signal and $n(t)$ is additive random noise. Consider noise is additive Gaussian white noise, it is demonstrated that a approximate unbiased estimation of desired signal $x(t)$ can be produced by TFPF[7].

TFPF is implemented on seismic data trace by trace. First, one-trace of seismic data $s(t)$ is encoded by FM modulation as instantaneous frequency of unit amplitude analytic signal, which can be written as

$$z(t) = e^{j2\pi\mu\int_0^t s(\lambda)d\lambda} \tag{2}$$

where μ is a scaling parameter similar to FM index. The problem of recovery of signal $x(t)$ is changed into the problem of estimation of IF of $z(t)$.

Then the IF estimation of analytic signal should be done to recover the seismic reflect signal. The method of IF estimation adopted by this paper is based on maximization of analytic signal's time-frequency distribution along the frequency axis, i.e.

$$\hat{x}(t) = \frac{\arg\max_f [Wz(t,f)]}{\mu} \tag{3}$$

Where $Wz(t,f)$ denotes the time-frequency representation of analytic signal z(t) and the signal $\hat{x}(t)$ denotes the filtered seismic reflect signal of one trace.

2.2. Reduced Bias Window Length

The assumption that IF is linear is important to obtain a unbiased estimation. However, the seismic reflect signal is nonlinear function of time, which means encoded analytic signal with a polynomial IF. The WVD of analytic signal exhibits significant concentration around the signal's IF, but the peak of the function may lie away from the true IF, which produces the deterministic bias of the signal estimate. So the Pseudo WVD, the version of window of WVD, is adopted here. It is written as

$$Wz(t,f) = \int_{-\infty}^{\infty} h(\tau) z\left(t+\frac{\tau}{2}\right) z^*\left(t-\frac{\tau}{2}\right) e^{-j2\pi f\tau} d\tau \tag{4}$$

Where $h(\tau)$ is windowing function. The rectangular windowing function is adopted in this paper.

It is shown that the deterministic bias of the signal estimate may be significantly reduced by minimizing data window length of the pseudo WVD and increasing the sampling frequency [6]. The maximum of the bias occurs at peak or valley of seismic reflect signal for the nonlinearity exhibited in window length. The relationship between bias, window length, sampling frequency and the dominant frequency of seismic data is derived for the worst bias, which is expressed as

$$WL \le \frac{0.384 f_s}{f_d} \tag{5}$$

where f_s and f_d denote the sampling frequency and dominant frequency ranged from 20Hz to 40 Hz respectively.

3. PERFORMACE OF TFPF FOR SEISMIC DATA

3.1. Synthetic Seismic Data

The seismic events in synthetic seismic data satisfies the hyperbolic time-distance equation

$$t^2 = t_0^2 + \frac{x^2}{v_{RMS}^2} \tag{6}$$

where x is the group interval chosen as $x = 10m$, v_{RMS} is the root mean squared velocity (RMS velocity), and t_0 is arrival time. The seismic reflect signal is modeled by Ricker wavelet. The synthetic seismic data with sampling frequency 1000Hz contained 40 traces and 2048 samples every trace. To simulate complex geological structure, 4 seismic events are included in seismic data shown in Fig.1(a) and white Gaussian noise (WGN) with different power is then added to this data. The noisy seismic data shown in Fig.1(b) shows that the seismic events are smeared by WGN.

TFPF is tested on synthetic data using a window length of 13 sample points PWVD, the filtered signal shown in Fig.1(c) shows the good performance in filtered data. The random noise exited in Fig.1(b) is attenuated and amplitude of filtered the signal is enhanced, which improved the SNR in filtered data. From Fig1.(d) where the trace 35, 25, 15 of first event are chosen for comparing the variety on waveform and frequency spectrum of record before(solid line) and after(dashed line) TFPF. The resulting shows that the waveform of filtered signal is approximately same as the true signal and the range of frequency of the filtered data is similar to that of true signal. The SNR calculated on each events (L1, L2, L3, L4) shown in Table 1 shows the significant improvement in filtered data.

3.2. TFPF for Common Shot point Seismic Data

TFPF is tested on common shot point seismic data. The seismic data has been recorded for 6 second, using sampling frequency 250 Hz. The seismic data shown in Fig.2(a) contained the strong random noise, which distributed in whole figure, especially concentrated in square 1, 2, 3. The random noise make the valid seismic events ineligible, broken, even smeared.

TFPF with 13 samples window length PWVD is implemented on the common shot point data trace by race, the filtered data shown in Fig.2(b). We can see that the noise in square1~3 is removed. The seismic events in filtered data become clear by removing most random noise in seismic data. Signal enhancement is also presented in the filtered data, which can be seen from Fig.3.

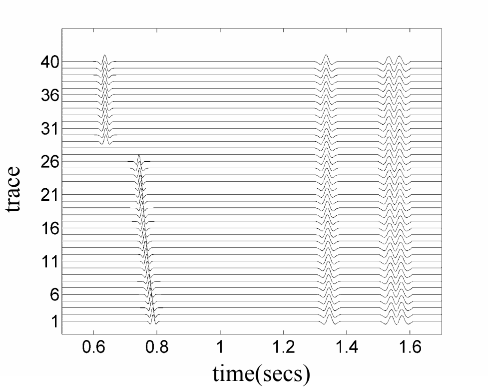


Fig.1 (a) synthetic seismic data

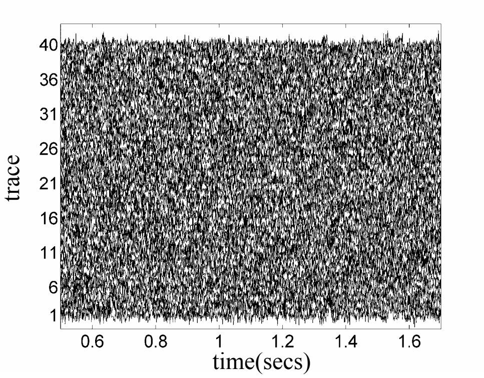


Fig.1 (b) noisy synthetic seismic data

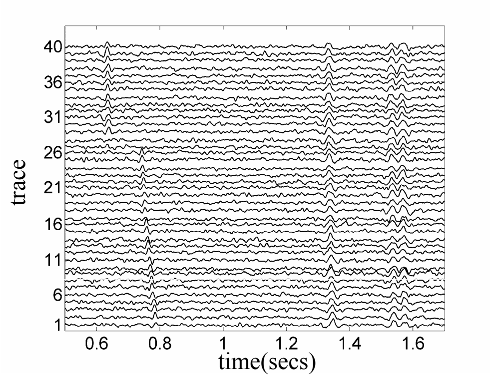


Fig.1 (c) filtered synthetic seismic data

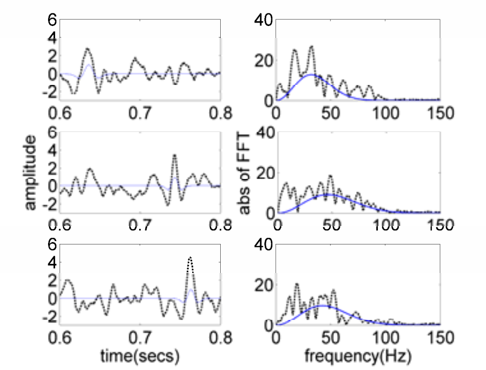


Fig.1(d) the trace 35, 25, 15 of first event and their frequency spectrum

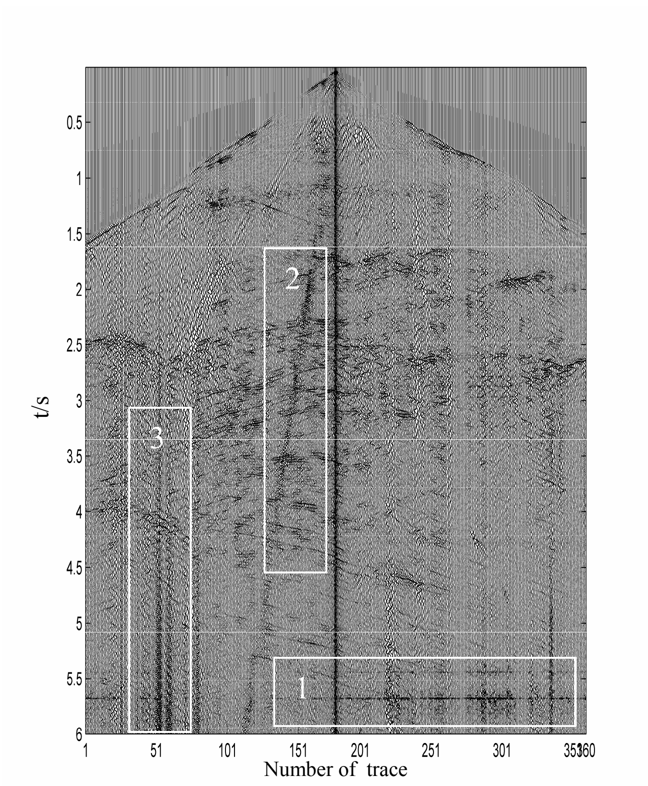


Fig.2 (a) common shot point seismic data

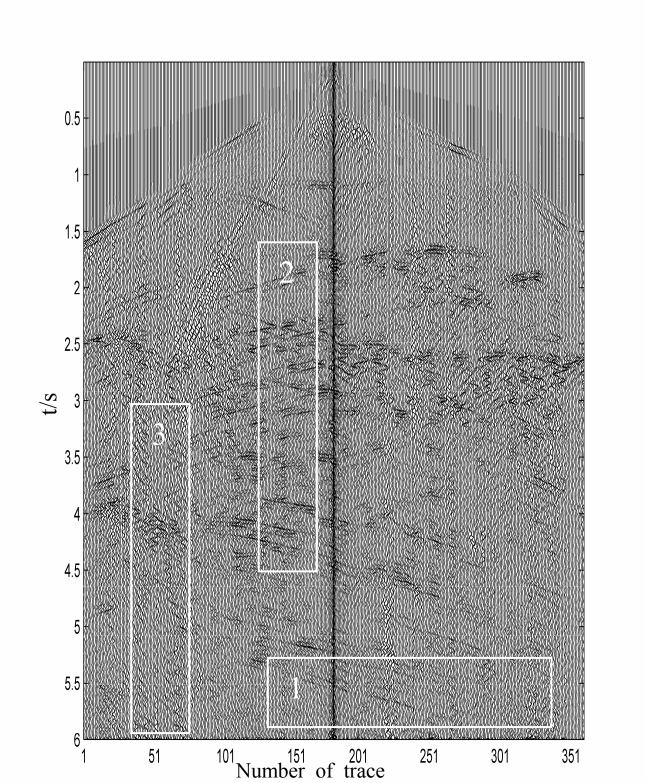
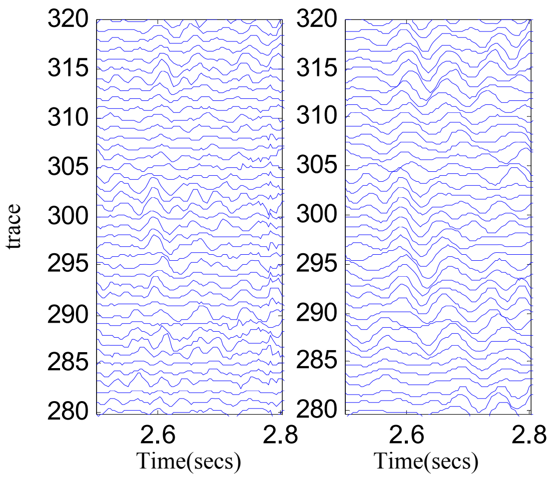


Fig.2 (b) filtered common shot point seismic data



(a) (b)

Fig.3 signal enhancement in seismic data.
(a)seismic data without TFPF. (b) filtered seismic data

Table 1 SNR computed on synthetic seismic data

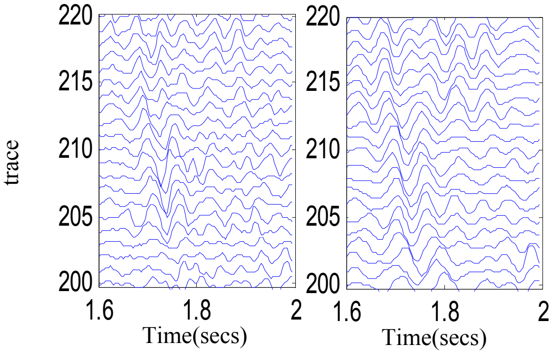
SNR(dB)	L1	L2	L3	L 4
raw	-2.4	-2.0	-1.3	-1.7
filtered	7.4	8.2	9.4	7.4

Comparing the resulting before and after TFPF, it shows that amplitude of seismic reflect signal is stronger than that of background noise in filtered data. While the similar level amplitude exhibits in raw seismic data. The improved continuity between wavelets of seismic events also is observed by comparing the filtered data shown in Fig.4(b) with the original seismic events shown in Fig.4(a). The events occurring between 2.2 second and 2.6 second in Fig.4(a) are interrupted by random noise which become continuous in Fig.4(b). The improved continuity makes the identification of seismic events easy.

The SNR computed on seismic data in square 1(Sq.1), Fig.2 and Fig.3 before and after TFPF (in Table 2) indicates good performance in improved SNR by using TFPF for seismic data. The method ensures the time efficiency.

4. CONCLUSIONS

Using FM modulation signal encoding and taking the peak of WVD of analytic signal, the TFPF is applied to recover seismic event embedded in additive random noise. Reduced window length pseudo WVD is used to obtain an unbiased estimation of seismic reflect signal. Testing on synthetic seismic data and common shot point data shows better performance in recovery of seismic events by removing noise and enhancing signal. The improved SNR, continuity of seismic event can obtained in filtered seismic data which leads the clear recovery seismic events.



(a) (b)

Fig.4 the improved continuity in seismic data.
(a)seismic data without TFPF. (b) filtered seismic data

Table 2 SNR on filtered common shot point data

SNR(dB)	Sq.1	Fig.3	Fig.4
raw	-0.3	1.6	3.4
Filtered	1.7	3.9	5.6

5.ACKNOLWLEDGEMENTS

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