Fourier transform and correlation analysis for CSEM data processing

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Abstract: Controlled Source Electromagnetic Method (CSEM) has the advantages of large depth of exploration and high efficiency. It has a wide range of applications in resource exploration and engineering surveys. However, CSEM data is often contaminated by strong cultural noise. In this paper, a novel method for CSEM data processing is proposed by combining the Fourier transform and correlation analysis. First, the observed data is performed by the Fourier transform, and the power-line noises are accurately removed in the frequency-domain. Second, the inverse Fourier transform is performed to the de-noised spectrum. Third, the correlations between transmitted and received data are calculated to quantitatively evaluate the data quality. Finally, high quality received data are selected by setting a proper threshold of correlation. We applied our approach to measured CSEM data. As a conclusion, the results obtained using our scheme are greatly improved over the previous.

1. Introduction
CSEM replaces natural sources with artificial sources and has higher anti-interference ability. It has been widely used in shale gas exploration, metal ore exploration and engineering geophysical exploration (Yang et al., 2017). With the development of civilization, it is inevitable that the observed CSEM data are interfered by various strong cultural noises (Mo et al., 2017; Liu et al., 2017; Yang et al., 2018). In this paper, the Fourier transform and correlation analysis are combined to propose a new controllable source data processing method. The paper firstly introduces the basic principle of removing the power-line noise based on the Fourier transform and evaluating the data quality based on correlation analysis. Then, the method is applied to the processing of CSEM data collected in Huidong County, Sichuan Province. Finally, the full text is summarized.

2. Theory and Methods

2.1. Power-line noise removing using Fourier transform
Power-line noise is the most common cultural noise during the acquisition of CSEM data (Tang et al., 2018). In this paper, we propose a new approach for power-line noise removing based on the Fourier transform. Suppose \( x \) is the signal to be processed with \( N \) sampling point, \( f_s \) is the sampling frequency
of \( x \). \( X \) is the spectrum sequence of \( x \) obtained using Fourier transform. The resolution of \( X \) can be expressed as:

\[
\Delta f = \frac{f}{N}
\]

The position of a certain frequency component in the sequence \( X \) can be written as:

\[
L_j = f + \Delta f + 1 = f \times \frac{N}{f_s} + 1
\]

The positions of power-line noise (50Hz) and its harmonic components in the sequence \( X \) are:

\[
L_{50n} = (50 \times n) \times \frac{N}{f_s} + 1, \quad n=1, 2, 3..., n<\frac{f_s}{50}-1
\]

Assuming that the amplitude of power-frequency interference in frequency domain is \( \mu \times \Delta f \), the minimum and maximum frequency of the power-line noise should be:

\[
d_1 = (50n - \mu \times \Delta f) \times \frac{N}{f_s} + 1
\]

\[
d_2 = (50n + \mu \times \Delta f) \times \frac{N}{f_s} + 1
\]

To remove the power-line noises, the only thing need to be done is to zero the amplitudes corresponding to those frequencies, that is:

\[
X \left\{ \left[ (50n - \mu \times \Delta f) \times \frac{N}{f_s} + 1 \right] : \left[ (50n + \mu \times \Delta f) \times \frac{N}{f_s} + 1 \right] \right\} = 0
\]

2.2. Evaluation and selection of CSEM data based on correlation analysis

Correlation analysis has been used in seismic signal processing, MT signal quality estimation and IP signal processing (Rouby et al., 2000). In CSEM, transmitted and received signals are highly correlated. Therefore, the correlation analysis is effective for data evaluation of CSEM data. In our scheme, the correction is calculated as (Liu et al., 2017):

\[
C = \frac{\sum_{i=1}^{N} (R_i - \langle R \rangle)(T_i - \langle T \rangle)}{\sqrt{\sum_{i=1}^{N}(R_i - \langle R \rangle)^2 \sum_{i=1}^{N}(T_i - \langle T \rangle)^2}}
\]

Where \( R_i \) is the spectrum of the \( i_{th} \) cycle in received CSEM data, \( T_i \) is the spectrum of the \( i_{th} \) cycle in transmitted data, the symbol \( \langle \quad \rangle \) represents the average of all data. Usually, the higher the correlation, the better the data quality.

2.3. Steps of the proposed method

As shown in Figure 1, first, the observed data is performed a Fourier transform, and the power-line noises are accurately removed in the frequency-domain. Second, an inverse Fourier transform is performed to the de-noised spectrum. Third, the correlations between the transmitted and received data are calculated to quantitatively evaluate the data quality. Finally, high quality received data is selected by setting a proper threshold of correlation.
### 3. Case studies

To verify the validity of the presented method, we applied our approach to noisy CSEM data which was collected in Huidong city, Sichuan Province. As shown in Figure 2, raw time-series are contaminated by strong cultural noise, including power-line noise and impulsive noise. After applying the proposed method mentioned in section 2.1, power-line noises are completely removed. Regular square wave can be found in the time-series. However, method proposed in section 2.1 is ineffective for impulsive noise. After applying the correlation analysis illustrated in section 2.2, time-series which polluted by impulsive noise are completely discarded. The rest is a regular pseudo-random square wave signal. As shown in Figure 3, there are outliers in the raw curves between 1 Hz and 4Hz, the new results obtained by the proposed method are a great improvement over the previous.
Figure 2. Measured time-series segments
(a) Origin (red line) and Fourier transform de-noised (blue line) data;
(b) Selected data

Figure 3. Apparent resistivity curves of the real station L1-3 in Sichuan

4. Conclusions
In order to improve the signal-to-noise ratio of CSEM data, this paper proposes a new CSEM data processing method based on the Fourier transform and correlation analysis. We draw the following conclusions:

(1) The proposed method could accurately remove the power-line noise and pick out high signal-to-noise ratio data from the data contaminated by strong cultural noise. This method was also an effective method for quantitatively evaluation of CSEM data.

(2) With our proposed data-processing approach, the data receiver could be greatly simplified.

(3) This method could be used for the processing of all periodic signals.

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