Orthogonal matching pursuit algorithm and power line noise suppression of magnetotelluric signal

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Abstract. Power-line noise is mainly comes from power systems and has become one of the most common noises during the acquisition of magnetotelluric (MT) signal, its components including a fundamental frequency signal and a lot of odd harmonics. There are trap circuits designed in most of the acquisition instruments to separate these noise, however, the fundamental frequency of the power line noise will fluctuate with the changing of load current, but the center frequency of the trap circuits are fixed, hence the MT data are still seriously disturbed by the power line noise. To mitigate the disturbance of power line noise, a novel denoising method was proposed based on orthogonal matching pursuit (OMP) algorithm. Semisynthetic experiments and real data obtained from Lu-Zong ore-concentration district illustrate that the proposed method can effectively suppress the power line noise while remain the useful MT signal, the apparent resistivity and phase curves are greatly improved over previous.

1. Introduction
Magnetotelluric sounding is an indispensable method for deep mineral resources exploration and many other fields. However, MT signal observed on the surface of the earth are extremely weak, that makes magnetotelluric sounding susceptible to cultural noises. As one of the most common cultural noises during the acquisition of MT data, power line noise has plagued geophysicists for decades [1, 2]. To suppress power line noise, there are trap circuits designed in most of the acquisition instruments, however, the fundamental frequency of the power line noise is changeable with the fluctuate of the load current, hence the MT data are still seriously disturbed by the power line noise.

In recent years, greedy algorithms have received much attention in signal processing, but it gets little attention in the processing of MT signal. MT signal is non-stationary and random [3, 4] while power line noise is regular or periodic and the amplitude of power line noise is much stronger than useful MT signal, thus makes it possible to identify power line noise accurately and to exclude the power line noise from noisy MT signal. This paper mainly discusses the suppression of power line noise in MT signal by using of OMP algorithm.

2. Theory and method

2.1 Orthogonal Matching Pursuit Algorithm
Traditional sparse representation is based on orthogonal basis, such as Fourier and wavelet, however, linear expansions in a given orthogonal basis are not flexible enough. In 1993, an algorithm called matching pursuit (MP) was proposed, MP algorithm decomposes any signal into a linear expansion of waveforms that are selected from a redundant dictionary. Since the redundant dictionary is not limited, MP is a very flexible signal sparse representation method [5]. By modifying matching pursuit, an improved algorithm called orthogonal matching pursuit (OMP) was proposed. The selected atoms in OMP are orthogonal, that lead to a faster convergence [6]. OMP algorithm is used for signal reconstruction and denoising extensively [7, 8].

2.2 Redundant dictionary
To subtract the power line noise from raw MT signal, the redundant dictionary is consist of sine atoms, cosine atoms and wavelet atoms. Sine atoms and cosine atoms are used to match the stationary harmonic components, wavelet atoms are used to match non-stationary periodic components. In order not to lose the useful MT signal, only low frequency wavelet atoms of coiflets 3 are used, the decomposition layer number is 4 [9].

2.3 Flow chart of signal processing

![Flow chart of signal processing](image)

Figure 1. Procedures of the data processing
The procedures of the data processing are showed in Figure 2. Firstly, since the amount of MT data is very large, usually up to millions, MT data set is segmented before sparse decomposition is performed. Secondly, noisy raw data are decomposed by using of the designed redundant dictionary and the greedy algorithm of OMP. Subsequently, filtered data segments are reconstructed. Finally, reconstructed MT data are used to calculate apparent resistivity and phase.

3. Semisynthetic experiments
In this section, we combines good real MT data set with synthetic noise, subsequently, the procedures showed in Figure 1 are used to separate the real data set from the mixed noisy data.

3.1 Single-frequency Harmonic Noise Experiment
Figure 2 shows the results of single-frequency harmonic noise experiment. Where (a) is the original MT data set, which is not affected by strong noise; (b) is the noisy data obtained by combining (a) with synthetic 5 Hz single-frequency harmonic noise, the peak amplitude of the noise is 2000; (c) is the reconstructed signal using the method showed in Fig.1; (d) is the difference between (a) and (c).
As shown in Figure 2, the amplitude of the harmonic noise is significantly larger than original MT signal, original MT signal are completely corrupted by the harmonic noise. By using the procedures showed in Figure 1, harmonic noises are suppressed significantly, the difference between original and reconstructed MT signal is very small.

### 3.2 Multi-frequency Harmonic Noise Experiment

In this experiment, synthetic noises including a 50 Hz fundamental signal and its six odd harmonics, \(150 \text{ Hz}, 250 \text{ Hz}, 350 \text{ Hz}, 450 \text{ Hz}, 550 \text{ Hz}\) and \(650 \text{ Hz}\). The amplitude of the fundamental signal is 18000, the amplitude of the other harmonics decreases regularly as the frequency increases. Figure 3 shows the results of multi-frequency harmonic noise experiment. Where (a) is the original MT signal; (b) is the noisy signal obtained by combining signal (a) with synthetic power line noise; (c) is the reconstructed signal using the proposed method; (d) is the difference between (a) and (c). As can be seen from Figure 3, by using the proposed method, multi-frequency harmonic noise can also be suppressed effectively.
4. Case studies
A real MT data set (site S1) gathered in Lu-Zong ore-concentration district were used to test the procedure. MT data in this site was observed using V5-2000, according to field records, there is a power transformer near the site and no other obvious noise sources. Analysis from the observed MT time series, we found MT data in this site contains strong periodic harmonic noise, obviously, it is contaminated by power line noise.

Figure 3. Results of multi-frequency harmonic noise experiment

Figure 4. Apparent resistivity and phase curves of site S1. (a) Original curves, (b) filtered curves.
Figure 4 shows the apparent resistivity and phase curves of site S1, the left panels are the results obtained from raw data, right panels are the results obtained from the same data set but after applying the proposed method. Curves 1 represents the $yx$ component, curves 2 represents the $xy$ component. All curves on the left panels are severely distorted around 150 Hz. As expected, curves on the right
panels are a significant improvement over previous results.

5. Conclusions
To suppress power line noise in MT signal, this paper presented a new signal processing method based on OMP algorithm and a designed redundant dictionary. Semisynthetic experiments and real data obtained from Lu-Zong ore-concentration district illustrate that the proposed method can effectively suppress power line noise in MT data. Apparent resistivity and phase curves obtained using the proposed method is a significant improvement over previous results.

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