Processing of noise contaminated magnetotelluric data using digital filters based on MATLAB

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Abstract. Magnetotelluric (MT) method is known as an effective geophysical method for imaging the condition of the subsurface resistivity distribution, especially in the geothermal system. However, this method is very sensitive to noise. The noise can occur due to mechanical activity such as vibration and electrical activity generated by powerline electric current near the point of measurement. To eliminate this noise is used digital filter consisting of despike filter and notch filter. Despike filter is used to eliminate irregular spike noise, while the notch filter is used to remove regular powerline noise. Furthermore, D+ can be applied to enhance the impedance data trend. Both of filters and D+ feature are built and then arranged into MTFilter program. The result of data processing using MTFilter program shows the improvement of MT data quality. Moreover, the inversion processing results of MT field data shows the resistivity distribution of structure which is more reliable with the characteristics of the geothermal system.

Keywords: Digital filter, magnetotelluric (MT), powerline noise, spike noise, D+

1. Introduction

The magnetotelluric (MT) method is a passive electromagnetic technique involving measurements of electric field fluctuations, E, and magnetic fluctuations, B, in an orthogonal direction beneath the surface of the Earth [1]. The MT signal from measurement are usually affected by noise. Noise is an electric field component or magnetic field that is not interconnected with the original signal [2]. The effect of noise on MT data can certainly influence the value of signal to noise ratio and the quality of MT data so it can lead to misinterpretation of MT data result.

The type of noise that usually appears in the MT data can be categorized based on its influence within a certain time, such as regular noise and irregular noise. Regular noise is a noise that occurred in a certain frequency range such as power line. Power line noise arising from the transmission and distribution system of AC power. Meanwhile, irregular noise is a noise that appeared in an uncertain frequency range. Irregular noise can arise from movement of vehicles that generate magnetic field noise due to vibrations propagated through the soil [3].

The main purpose of this research is to develop a Matlab based program to reduce the effect of noise on MT data so that the rho-phase curve is more reliable to describe the distribution of electrical properties below the earth's surface. The initial process of building a program which is called MTFilter is performing processing on MT synthetic data which is then applied to MT real data. Synthetic data...
are created by adding a clean signal with regular noise from power line noise and also irregular noise such as spike noise. The synthetic signals are then filtered using pre-made filters to see the benchmarks of the program in eliminating noise. After obtained the expected qualifications, the filters are built into the MTFilter program. Then this program is applied to MT real data by conducted 1-D and 2-D inversion of MT data.

2. Methodology synthetic data testing

2.1. Notch filter

Noise generated by power line has frequency characteristics of 50 or 60 Hz. This noise is overcome using notch filter. This filter removes the frequency band in a narrow range so that the spectrum changes slightly. This filter can be made using a little variation on the type of all-pass filter. In the all-pass filter, poles and zero values have the same relative distance (logarithmic) of the unit circle. When the value of zero is closer to the loop, then the frequency at which zero lies is the cancelled spectral value of the input data. An example of the response of the notch filter to eliminate 50 Hz frequency data and odd multiple shown in the figure 1 [4].

There are two synthetic time series data is created. Those signal has main characteristics which the sampling frequency is 1600 Hz and follows the sinusoidal wave equation $y = A \sin (2\pi ft)$ where $f$ is frequency with four main frequencies (100, 219, 375, 563) Hz, $t$ is time and $A$ is amplitude with the value of amplitude is 1. The time series data are formed in the time domain then after proceed by FFT, it converted into frequency domain as shown in figure 2.

![Figure 1. Notch filter response to eliminate 50 Hz frequency data and odd multiples.](image1.png)

![Figure 2. Time series data with main frequency (100, 219, 375, 563) Hz. (a) Time domain, and (b) The frequency domain.](image2.png)
Furthermore, to verify the ability of notch filter, those signal is added with two different types of signals, there are sinusoidal wave in figure 3a and square wave in figure 3c with the magnitude of frequency is 50 Hz and the value of amplitude is 4. It can be observed that there is noise that has frequency 50 Hz in figure 3b for the sinusoidal signal and figure 3d for the square signal. The notch filter results for the sinusoidal signal is shown in figure 3e and square signal in figure 3f. It shows the noise which has 50 Hz frequency are successfully eliminated by notch filter.

2.2. Despike filter
Irregular noise can be generated from disturbance due to vehicle movement which will result in electric and magnetic field. The magnetic coil change of about 0.002° causes a magnetic field change of 1 nT and 1 meter of 1 Hz vibrating electric wire with amplitude of 1 mm can cause a change of 0.5 μV [3].
Despike filter has been developed to reduce the irregular noise. It was done by determining the bad data segment over a certain time interval range with autocorrelation. Autocorrelation is principally calculated the normalized value of the times product of a signal by itself in the variation in the initial time difference.

In the testing process to eliminate irregular noise, the authors create a synthetic of clean time series data. The clean signal has characteristics of sampling frequency is 1600 Hz and follow the equation $y = A \sin \left( \frac{2 \pi ft}{590} \right)$ where $f$ is frequency, $t$ is time and $A$ is amplitude with amplitude of 0.8 and a frequency of 100 Hz. Then the clean signal is given a noise in the form of random noise that has random value within range -6 and 6 magnitude at 1000 initial data to generate a spike noise. The resulting signal is shown in figure 4.

![Figure 4](image.png)

**Figure 4.** Synthetic data for irregular noise, (a) clean synthetic signal from noise, and (b) synthetic signal given random noise.
The initial stage of the scheme to remove noise on the despike filter is to detect the signal part which is influenced by noise using the autocorrelation. The sampling of synthetic signals is divided into 4 segments as shown in figure 5a. Then each segment is calculated for each autocorrelation value as a reference to determine the signal part containing spike noise. When the autocorrelation value is lower than 0.5 then this segment determined as noise and vice versa.

The noise spike on the signal is detected as shown in figure 5a. It is shown in three first segment that the value of autocorrelation is below than the average RMS autocorrelation. So, it was detected as a noise. The next step is to reduce the noise. The filter process was done by extrapolating the segments with autoregressive. The process obtained from despike filter results can be seen in figure 5b. The result shows the spike noise in the first three segment are already eliminated, and the value of autocorrelation is increased.

(a)

(b)

Figure 5. Experiment on synthetic data with despike filter for irregular noise, (a) segment determination on synthetic data with autocorrelation feature, (b) filtered data by using despike filter.
2.3. Applying MTFilter to MT real data

The MTFilter program work mechanism can be described in figure 6. MT real data from the acquisition is in the form of a raw time series data conducted using Phoenix Geophysics instrument. The raw data contained is magnetic field data on x, y and z components and electric field data on x and y components. The data is stored in MTU Binary file format file. So, it is needed a data conversion to convert MTU Binary file format to csv ASCII file in order to be processed with MTFilter which is Matlab based program.

Then the time series data which is contaminated by noise is reduced using notch filter and despike filter. After the clean data was obtained then FFT process is done to get frequency domain data. Furthermore, the data was calibrated using calibration box. Moreover, the impedance complex transfer function is calculated. After that, it is optimized the impedance data with D+ method.

The D+ processing technique is a method to ensure a physically valid response (minimum phase) of data that has a 1D response characteristic [5]. The D+ analysis can correspond to a valid 1D response physically considered by [6]. D+ is usually described in complex c-response numbers associated with apparent resistivity and phase as [6].

\[
c(\omega) = (\rho_a / \mu_0 \omega)^{1/2} \exp[i(\phi / 2)]
\]

where \(\omega\) is the angular frequency, \(\rho_a\) is apparent resistivity, \(\mu_0\) is the permeability of the empty space and \(\phi\) is phase. In the end of processing, rho-phase curve can be obtained.

![Figure 6. MTFilter program working mechanism](image-url)
3. Results and discussion

Figure 7 shows the comparison result of resistivity – phase curve before and after proceed by MTFilter program. It is shown that the trend of curves before proceeding with MTFilter program has a random trend in the entire frequency as shown in figure 7a. Otherwise, the data shows a good and more reliable trend after conducting a treatment by MTFilter program as shown in figure 7b.

To recognize the effectiveness of MTFilter program in enhance the quality of the data in order to get a better image of the real geothermal system, then 1-dimensional and 2-dimensional inversion were carried out. The inversion was done using WinGLink software that made by Schlumberger. The result of a 1-dimensional inversion is shown in figure 8.

The 1-dimensional inversion of data without proceed using MTFilter program is shown in figure 8a. Generally, the result shows that the area is dominated by a high resistivity layer which indicated with blue colour. Meanwhile, the result of 1-dimensional inversion of MTFilter data shows more realistic interpretation as shown in figure 8b. It shows three different layers, that represent the geothermal system. A low resistivity layer in red-orange colour is detected in near surface as a clay cap layer. Furthermore, this layer underlying a high resistivity layer which probably interpreted as a reservoir. Moreover, a highest resistivity layer is indicated by blue colour as a basement.

In addition, figure 9 shows the 2-dimensional inversion results of data without proceed using MTFilter and after proceeding. Figure 9a shows that the result could not well distinguish the layers. It seems the subsurface is dominated by low resistivity layer that indicated by red colour. Otherwise, figure 9b shows a good result which can observe a three different layer. This result supports the interpretation of 1-dimensional inversion.

![Figure 7. Comparison results of apparent resistivity and phase curve processing by MTfilter (a) before processing, (b) processed MTFilter.](image-url)
Figure 7 (continued). Comparison results of apparent resistivity and phase curve processing by MTfilter (a) before processing, (b) processed MTFilter.

Figure 8. Inversion 1-dimension result (a) original data, (b) MTFilter data.
Figure 8 (continued). Inversion 1-dimension result (a) original data, (b) MTFilter data.

Figure 9. Inversion 2-dimension result (a) original data, (b) MTFilter data.
4. Conclusion
The results of MTFilter data shows more reliable results for interpretation. Synthetic data prove that power line noise can be overcome using notch filter and spike noise can be removed with despike filter. Then, when MTFilter applied to real data, the result of rho-phase curve shows better trend result. This is reinforced by result of 1 dimensional and 2 dimensional inversions which is shown a better result of geothermal system structure.

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