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Depth and structural index estimation of 2D magnetic source using correlation coefficient of analytic signal

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ABSTRACT

We presented using the correlation coefficient of the analytic signal of real data and the analytic signal of synthetic data generated by the assumed source to estimate the structural index and the depth of the source. First, we assumed that the causative sources are located at different locations in the underground and the structural index of the assumed source is changed from 0 to 3, and then we separately compute the correlation coefficients of the analytic signal of the measured data and the analytic signal of the anomaly generated by each assumed source, the correlation coefficient can get the maximum value when the location and structural index of the assumed source are consistent with the real source. We tested the correlation coefficient method on synthetic noise-free and noise-corrupted magnetic anomalies, and the inversion results indicate that the new method can successfully finish the inversion of magnetic data. We also applied it to measured magnetic data, and we obtain the structural index and the location of the source.

1. Introduction

Correlation coefficient is first used to represent the correlation of gravity and magnetic anomalies in the area of geophysics, and the correlation analysis of gravity and magnetic anomalies combined with other geological and geophysical information can be useful in the interpretation of geophysics data. Chandler et al. (1981) presented a quantitative approach based on Poisson's theorem to compute the correlation coefficient of gravity and magnetic anomalies, and then applied the method to the gravity and magnetic anomalies around Michigan and Lake City. Many people also used this method to research the correlation of gravity and magnetic anomalies of an area (Düzgit et al., 2006; Frese et al., 1982; Turgut and Eseller, 2000). Analytic signal is a popularly used method in the interpretation of magnetic anomaly, which is insensitive to magnetization direction in two dimensions (Bastani and Pedersen, 2001; Ma and Du, 2012; Nabighian, 1972), so it can be used in case of remanet magnetization (Keating and Sailhac, 2004). The analytic signal methods are used widely in the interpretation of real magnetic data (Hsu et al., 1998; Salem and Ravat, 2003; Salem et al., 2004).

In this paper, we suggested using the correlation coefficient of the analytic signal of real magnetic anomaly and the analytic signal of the anomalies calculated by assumed sources to estimate the structural index and the location of the source. We tested the new method on synthetic and real magnetic anomalies.

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1.1. The new method

The 2D analytic signal (AS) of magnetic anomaly M (Nabighian, 1972) can be expressed as

$$AS(x,z) = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \tag{1}$$

where, $\partial M/\partial x$ and $\partial M/\partial z$ are the horizontal and vertical derivatives of the magnetic anomaly, respectively. The 2D analytic signal of the magnetic source that is located at horizontal location x_0 and depth z_0 can be written as

$$AS(x,z) = \frac{k}{\left[(x-x_0)^2 + (z-z_0)^2\right]^{(m+1)/2}} \tag{2}$$

where, k is a constant value, and m represents the structural index of the source, $m=0$ for a contact, $m=1$ for a vertical dike, $m=2$ for a horizontal cylinder and $m=3$ for a dipole.

The correlation coefficient of the analytic signal of the real magnetic data and the analytic signal of the data generated by the jth assumed source can be expressed as

$$R_j = \frac{\operatorname{cov}\left[AS_r, AS_j\right]}{\sqrt{D[AS_r]D\left[AS_j\right]}} \tag{3}$$

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where, AS_r represented the analytic signal of the real magnetic data, and the AS_j is the analytic signal of the data generated by the jth assumed source. $\mathrm{cov}\left[AS_r, AS_j\right] = \frac{1}{M}\sum_{i=1}^{M}\left[(AS_r)_i\left(AS_j\right)_i\right]$, $D(AS_r) = \frac{1}{M}\sum_{i=1}^{M}\left[(AS_r)_i\right]^2$, $D\left(AS_j\right) = \frac{1}{M}\sum_{i=1}^{M}\left[\left(AS_j\right)_i\right]^2$. M is the length of the window, and the center of the window is the horizontal location of the jth source.

We can compute the analytic signal of the real data AS_r by Eq. (1), and the AS_j can be computed by Eq. (2). We can get

$$AS_j(x,z) = \frac{k}{\left[\left(x-x_j\right)^2 + \left(z-z_j\right)^2\right]^{(m+1)/2}} \tag{4}$$

Bringing Eq. (4) into Eq. (3) with a simple rearrangement, we can get

$$R_j = \frac{\mathrm{cov}\left[AS_r, B_j\right]}{\sqrt{D[AS_r]D\left[B_j\right]}} \tag{5}$$

where, $B_j(x,z) = \frac{1}{\left[\left(x-x_j\right)^2+\left(z-z_j\right)^2\right]^{(m+1)/2}}$. The assumed source is distributed according to a certain rule, and the distribution of the assumed sources is shown in Fig. 1, so the coordinate (x_j, z_j) of each assumed source are known. We can compute the correlation coefficients of analytic signal of the real data and the analytic signal of the anomaly generated by each assumed source, and the correlation coefficient can get maximum value when the location and structural index of the assumed source are in accord with the real source.

2. Tests on synthetic magnetic anomalies

To test the feasibility of the new method, we apply it to magnetic anomaly of a vertical thin dike. The dike is located in the middle of the profile with top depth of 5 m. The inclination and declination of induced magnetic field are 60°and 0°, respectively, and the interval of the data is 1 m. Fig. 2a shows the magnetic anomaly of the dike. We use Fourier transform to compute the requisite derivatives of the magnetic anomaly, Fig. 2b shows the analytic signal of the data in 2a. The size of the subsurface is set to 100×10 m, and the interval of each assumed source is 1 m. We use Eq. (5) to compute the correlation coefficients, and the maximum values of correlation coefficients computed by different structural index are shown in Table 1. We can see that the correlation coefficients get maximum value when the structural index is equal to 1, so the source is a dike. Fig. 2c shows the correlation coefficients of the analytic signal in 2b and the analytic signal of the anomalies generated by the assumed sources with structural index of 1. The black cross marks the location of the maximum value, so we can ascertain that the horizontal location of the source is 50 m and the depth of the source is 5 m. The new method can provide the accurate results of the location and structural index of the source.

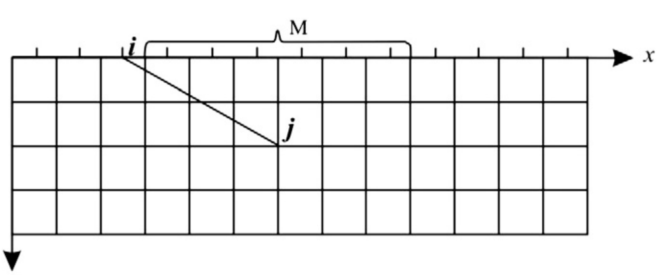

Fig. 1. The distribution of the assumed sources.

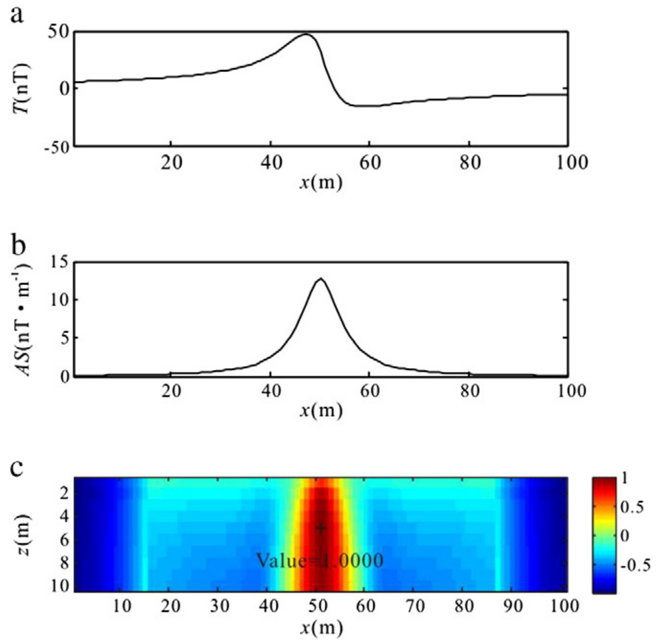

Fig. 2. (a) Noise-free magnetic anomaly generated by a dike model at a horizontal location of 50 m and a depth to the top of 5 m. (b) Analytic signal of the anomaly shown in 2a. (c) Correlation coefficient of analytic signal in 2b and the analytic signal of the calculated data with the structural index of 1.

In the interpretation of real data, the noise is a considerable factor. Fig. 3a shows the magnetic anomaly in 2a by adding random noise with mean zero and mean square deviation of 1.5 nT. Fig. 3b shows the analytic signal of the data in 3a. We found that the correlation coefficients get maximum values when the structural index is equal to 1.1. Fig. 3c shows the correlation coefficients of the analytic signal in 3b and the analytic signal of the data calculated by assumed sources with structural index of 1.1. The correlation coefficient map shows that the horizontal location of the source is 50 m and the depth of the source is 5.1 m. The inversion results are all close to the true values without applying any noise reducing techniques and certify the stability of the new method.

To test the availability of the new method, we apply it to composite magnetic anomaly generated by four adjacent dikes located at 5 m depth. The horizontal distance of adjacent dikes is increasing and the other source parameters are the same. Fig. 4a shows the magnetic anomalies of the dikes, and the horizontal locations of the dikes are marked by the black cross. Fig. 4b shows the analytic signal of the data in 4a. The experiment shows that the correlation coefficients get maximum values when the structural index is equal to 1. Fig. 4c shows the correlation coefficients of the analytic signal in 4b and the analytic signal of the data calculated by the assumed sources with structural index of 1.

Table 1
Correlation coefficients computed by different structural indicates.

Maximum value of correlation coefficient	Structural index (SI)
0.9421	0.7
0.9593	0.8
0.9805	0.9
1.0000	1.0
0.9785	1.1
0.9562	1.2