29. Schmucker-Weidelt Kolloquium fuer Elektromagnetishe Tiefenforschung, 27-30 September 2021, Online

Differencing magnetic gradient tensor system and its application in multiple dipole-like magnetic sources localization

Xuezhen Ding[1], Jialin Chen[2], Fujun Qi[3], Lanjun Liu[2], Yuguo Li[1]

1 College of Marine Geosciences, Ocean University of China, Qingdao 266100, China
2 College of Engineering, Ocean University of China, Qingdao 266100, China
3 College of Information Science and Engineering, Ocean University of China, Qingdao 266100, China

Differencing magnetic gradient tensor system

The Ocean University of China (OUC) EM group has developed a new type of differencing magnetic gradient tensor system (Fig.1), which consists of four fluxgate magnetometers, an attitude sensor, a magnetic field compensation system, and a data acquisition system. The tensor system can compensate the magnetic field in real time and measure the magnetic gradient for detection and positioning of magnetic sources.

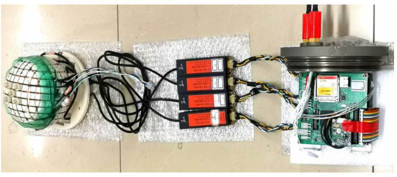

Fig 1. Differencing magnetic gradient tensor system.

Technical characteristic of tensor system

Magnetic noise floor: 10pt/rt(Hz)@1Hz;
Number of channels: 12;
Clock drift：less than 2ms/day;
Sampling Resolution :24 bit ;
Frequency range: DC-10Hz;
Power Consumption: 6W;
Baseline distance: 0.08 m.

Magnetic gradient tensor and normalized source strength

The magnetic gradient tensor G is the spatial change rate of three components of the magnetic field vector B along three mutually orthogonal axes.

$$\mathbf{G}=\begin{bmatrix}\partial/\partial x\\ \partial/\partial y\\ \partial/\partial z\end{bmatrix}\begin{bmatrix}B_x & B_y & B_z\end{bmatrix}=\begin{bmatrix}B_{xx} & B_{xy} & B_{xz}\\ B_{yx} & B_{yy} & B_{yz}\\ B_{zx} & B_{zy} & B_{zz}\end{bmatrix}$$

The magnetic gradient tensor G is symmetric and trace free, only five components of G are independent. Assuming a dipole-like magnetic source with a dipole moment of m=(m_x, m_y, m_z) located at (x_0, y_0, z_0) , The all five independent components at a measurement point (x_1, y_1, z_1) can be expressed as

$$\begin{bmatrix}B_{xx}\\ B_{xy}\\ B_{xz}\\ B_{yy}\\ B_{yz}\end{bmatrix}=\frac{\mu_0}{4\pi r^7}\begin{bmatrix}9xr^2-15x^3 & 3yr^2-15x^2y & 3zr^2-15x^2z\\ 3yr^2-15x^2y & 3xr^2-15xy^2 & -15xyz\\ 3zr^2-15x^2z & -15xyz & 3xr^2-15xz^2\\ 3xr^2-15xy^2 & 9yr^2-15y^3 & 3zr^2-15y^2z\\ -15xyz & 3zr^2-15y^2z & 3yr^2-15yz^2\end{bmatrix}\begin{bmatrix}m_x\\ m_y\\ m_z\end{bmatrix}$$

The normalized source strength (NSS) is defined as (Clark, 2012; Yin et al.,2016)

$$\text{NSS}=\sqrt{-\lambda_2^2-\lambda_1\lambda_3}$$

where λ_i $(i=1,2,3)$ are the eigenvalues of magnetic gradient tensor, and $\lambda_1>\lambda_2>\lambda_3$, $|\lambda_1|>|\lambda_2|$, $|\lambda_3|>|\lambda_2|$. Since NSS is isotropic around the magnetic dipole and independent of the magnetization direction, hence it can be adopted to detect the magnetic sources.

ACKNOWLEDGEMENTS

This work was funded by the Wenhai Program of QNLM under Grant 2017WHZZB0201 and the National Key R&D Program of China under Grant 2019YFC1408100.

Detection and localization of multiple magnetic sources

We propose a new method for the detection and localization of multiple magnetic sources. Firstly, we estimate the number of magnetic sources using tilt angle, then the approximate horizontal coordinates of magnetic sources are obtained by using NSS, finally the locations and moments of magnetic sources are calculated using the differential evolution (DE) algorithm.

(1) Estimating the number of dipole-like magnetic sources

The magnetic sources may be buried at different depths below the surface. We extended the potential field tilt angle (Miller & Singh, 1994) to magnetic vector data, which is defined in terms of the ratio of the vertical component to the horizontal component of the magnetic field.

$$tilt=tan^{-1}\left(B_z/\sqrt{B_x^{\,2}+B_y^{\,2}}\right)$$

(2) Estimating approximate horizontal coordinates of magnetic source

NSS is independent of the magnetization direction and falls off as 1/r⁴, where r is the distance from the magnetic source, so the NSS generated by each magnetic source is not strongly influenced by its adjacent magnetic sources. Thus, we can use the NSS to estimate the approximate horizontal coordinates of magnetic sources. The local maximum of the calculated NSS may be considered as the horizontal coordinates of magnetic sources

(3) Estimating the locations and moments of magnetic sources using DE algorithm

The differential evolution (DE) was used to estimate the locations and moments of the magnetic sources, including three parameters for the positions and three parameters for the magnitude and direction of the moments. These six parameters form a parameter vector which update in the optimization process until the magnetic gradient tensor of the inversion model fit the measured data well.

Field test

A field test was conducted. The survey area is 7m*7m, and the interval between the measurement points is 0.25 m. The magnetic gradient tensor system was used to measure the magnetic gradient tensor data. The magnetic sources 1 - 5 were composed of 1, 2, 4, 3 and 2 identical magnets, respectively. The true locations, estimated locations and moments of the magnetic sources are listed in Table 1. The locations of five magnetic sources are recovered by using the proposed method. The estimated magnetic moment of Source 3 is bigger than that of other sources as expected. The magnetic moment of Source 2 is almost equal to that of Source 5, which are both composed of 2 magnets.

Table 1 The Prearranged and estimated locations and moments of 5 magnetic sources.

	Dipole	x/m	y/m	z/m	I/°	D/°	m/Am²
Prearranged	1	1	6	0	/	/	/
	2	2.5	2.5	0	/	/	/
	3	3.5	3.5	0	/	/	/
	4	5	1.5	0	/	/	/
	5	5.5	5.5	0	/	/	/
Estimated	1	0.998	5.994	0.041	10.172	-88.846	16.260
	2	2.503	2.441	0.052	31.767	116.668	26.912
	3	3.479	3.477	-0.070	35.252	-25.442	73.197
	4	4.973	1.471	-0.022	18.762	97.218	43.083
	5	5.506	5.521	0.047	32.613	-90.102	28.689

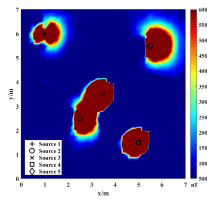

Fig 2. The measured magnitude of magnetic anomaly caused by magnetic sources.

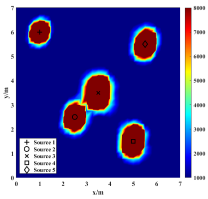

Fig 3. The calculated NSS using the gradient tensor.

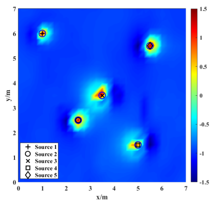

Fig 4. The calculated tilt angles. The blue circles represent the detected magnetic sources.

References

[1] D. A. Clark, "New methods for interpretation of magnetic vector and gradient tensor data I: eigenvector analysis and the normalised source strength," Exploration Geophysics, vol. 43, pp. 267-282, 2012.

[2] G. Yin, Y. Zhang, H. Fan, Z. Li, and G. Ren, "Detection, localization and classification of multiple dipole-like magnetic sources using magnetic gradient tensor data," Journal of Applied Geophysics, vol. 128, pp. 131-139, 2016.

[3] H. G. Miller and V. Singh, "Potential tilt-A new concept for location of potential field sources," Journal of Applied Geophysics, vol. 32, pp. 213-217, 1994.