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# A fast interpretation method of gravity gradiometry data based on magnetic dipole localization

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ABSTRACT

In this paper, we proposed a fast interpretation method for gravity gradiometry data, based on the magnetic dipole localization method. It could automatically and rapidly locate the horizontal and vertical positions of gravity targets without prior information. This method was successfully tested on synthetic data. Compared with gradient ratio method (tilt-depth) and Euler deconvolution, our method provided good performance in the gravity gradiometry data with high noise levels and superimposed fields. Point selection was processed among the inversion results to improve the resolution of our method. Statistical analysis and Gaussian fitting were also used to improve the stability and accuracy of the calculation. Finally, we applied this algorithm to gravity gradiometry data over Vinton Dome; the results are consistent with previous research in this area.



## 1. Introduction

Gravity and magnetic methods are used in diverse geological explorations, where one major purpose is to character the physical properties and spatial location of geological bodies. A fast interpretation method to locate and outline the central of interest is important in oil and gas exploration (Zeng et al., 2002), mineral exploration (Gupta and Grant, 1985) and near surface geophysical detection (Ravat et al., 2003). Interpretation techniques such as the Hilbert transform, analytic signal (Nabighian, 1972), local wavenumber (Thurston and Smith, 1997), and Euler deconvolution (Thompson, 1982) are widely used to estimate the horizontal location, depth, and edge of sources. Realizing the spatial localization of targets is one of the main objectives of potential field research.

Gravity gradiometry data measure the changes in the gravity field in three directions. This provides advantages over general gravity data, such as informative. In particular, gravity gradiometry data have a much higher resolution in inverting the spatial position and physical properties of geological bodies. Further, the introduction of a gravity moving platform has reinforced the utility of gravity gradiometry. A large number of inversion and interpretation methods have been developed for gravity gradiometry data dealing with the geometric information and physical properties of targets. Several examples include gradient invariants (Pedersen and Rasmussen, 1990; Murphy and Brewster, 2007; Dickinson et al., 2010), Euler deconvolution (Zhang et al., 2000; Mikhailov et al., 2007; Valentin et al., 2007; Beiki, 2010), the eigenvector of the gravity tensor (Mikhailov et al., 2007; Beiki and Pedersen, 2010), the tilt angle (Salem et al., 2013) and the Theta method (Wijins et al., 2005; Yuan et al., 2016) to enhance the edges of geological bodies, whereas balanced gradients have been used to recognize the source edges (Miller and Singh, 1994; Verduzco et al., 2004; Wijns et al., 2005; Cooper and Cowan, 2006, 2008; Lu and Ma, 2015). Cooper (2011) proposed a semiautomatic interpretation of gravity profile data which was generalized from magnetic tilt-depth (Salem et al., 2007). However, this method is sensitive to noise and the superimposed fields of two objects with different physical and geometry properties.

Recently, gravity gradiometry data have been used to interpret 3-D geological bodies (Li and Oldenburg, 1998; Oliveira and Barbosa, 2013). For instance, several 3-D inversion algorithms for gravity gradiometry data have been applied to interpret mineral exploration targets (Li, 2001; Zhdanov et al., 2004; Martinez et al., 2010, 2012) and salt bodies in a sedimentary setting (Jorgensen and Kisabeth, 2000; Routh et al., 2001; Silva Dias et al., 2011; Geng et al., 2014; Qin et al., 2016; Meng, 2016; Hou et al., 2016). These methods can be used to estimate the horizontal location, central depth, or edges of geological bodies. However, the theory and methods for the processing and interpretation of gravity gradiometry data that combine all the gravity gradient components and gravity field are still challenging. Moreover, the application of these data has been limited by large computing time and priori information needed for inversion. Therefore, it is important to develop new techniques for gravity gradiometry data inversion.

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The algorithm for the point localization of a magnetic dipole can be used to automatically and rapidly locate a magnetic source, and was first developed in 1972 (Wynn, 1972). Since then, the scope of the algorithm was expanded, and it can now be used to track a magnetic object in real-time. Frahm (1972) developed a method for the point-by-point localization of a magnetic dipole with an explicit solution. Wynn et al. (1975) created a method that can characterize the position and moment of magnetic field source from the observed first field derivatives at a single point. Based on the dipole-tracking algorithm of Wynn, Nelson (1988) noted that the errors in depth estimation are less than 10% if the smallest separation is more than twice the largest dimension of the body and developed a method to estimate the depth and horizontal location of the dipole. The tensor components can be continued upward, and the tracking algorithm will provide the correct geophysical information. A solution to the problem of magnetostatic location and identification of compact ferrous objects of arbitrary shape was developed by McFee et al. (1990). This performed well in tests using ferrous spheroid. Wynn (1995) used the gradient rate tensor measured by a five-axis magnetic gradiometer with a known velocity to locate the position of a magnetic source and discussed the uniqueness of this inversion method. Wynn (1997) further proposed that a unique solution for the magnetic moment vector and the relative position between the source and the field point can be obtained if either the magnetic field vector, or the rate of change of the gradient tensor and the relative motion of source and field point is known. Zhang (2000) indicated that the magnetic dipole algorithm localization is a special case of the Euler deconvolution method. Nara et al. (2006) proposed an algorithm and a compact sensor for the localization of a magnetic dipole. The algorithm was successfully applied to the synthetic and actual measured data.

In this paper, the inversion method for magnetic dipole localization was first extended to gravity gradiometry data based on Poisson's relation. This can automatically and rapidly locate the central positions of gravity targets. Our method showed good performance in the gravity gradiometry data of high noise level and superimposed fields, compared with gradient ratio method (tilt-depth) and Euler deconvolution. Finally, this method was applied to the airborne full-tensor gradient data of Vinton Dome. The result is consistent with the previous studies.

## 2. Method

The intensity of a magnetic dipole can be expressed as follows:

$$\mathbf{H} = \frac{1}{4\pi}\frac{3(\boldsymbol{m}\cdot\boldsymbol{n})\boldsymbol{n}-\boldsymbol{m}}{r^3} \tag{1}$$

where $r=|\mathbf{r}|$ is the distance from the source to the sensor. $\boldsymbol{n}=(\boldsymbol{r}/r)$ is the unit vector parallel to the source-sensor direction. $\boldsymbol{m}$ is the magnetic moment.

Let us consider the magnetic field at the point $\mathbf{r}+\mathbf{n}$dr. This is given by

$$\mathbf{H}' = \frac{1}{4\pi}\frac{3(\boldsymbol{m}\cdot\boldsymbol{n})\boldsymbol{n}-\boldsymbol{m}}{(r+dr)^3} \tag{2}$$

Because $\boldsymbol{n}$ and $\boldsymbol{m}$ are common to $\mathbf{r}$ and $\mathbf{r}+\mathbf{n}$dr. The direction of $\mathbf{H}'$ is parallel to that of $\mathbf{H}$. The total differential between $\mathbf{H}'$ and $\mathbf{H}$ is

$$\begin{aligned}\mathbf{H}'-\mathbf{H} &= \frac{1}{4\pi}(3(\boldsymbol{m}\cdot\mathbf{n})\mathbf{n}-\boldsymbol{m})\left(\frac{\partial}{\partial r}\frac{1}{r^3}dr\right)\\ &= -\frac{3}{r}\cdot\frac{1}{4\pi}\frac{3(\boldsymbol{m}\cdot\mathbf{n})\mathbf{n}-\boldsymbol{m}}{r^3}dr = -\frac{3}{r}\mathbf{H}\mathrm{dr}\end{aligned} \tag{3}$$

Further, the difference of the vector $\mathbf{H}$ can be written using the gradients of the magnetic field as

$$\mathbf{H}'-\mathbf{H} = \begin{pmatrix}\nabla H_x\cdot\boldsymbol{n}dr\\ \nabla H_y\cdot\boldsymbol{n}dr\\ \nabla H_z\cdot\boldsymbol{n}dr\end{pmatrix} = \begin{pmatrix}\frac{\partial H_x}{\partial x} & \frac{\partial H_x}{\partial y} & \frac{\partial H_x}{\partial z}\\ \frac{\partial H_y}{\partial x} & \frac{\partial H_y}{\partial y} & \frac{\partial H_y}{\partial z}\\ \frac{\partial H_z}{\partial x} & \frac{\partial H_z}{\partial y} & \frac{\partial H_z}{\partial z}\end{pmatrix}\boldsymbol{n}dr \tag{4}$$

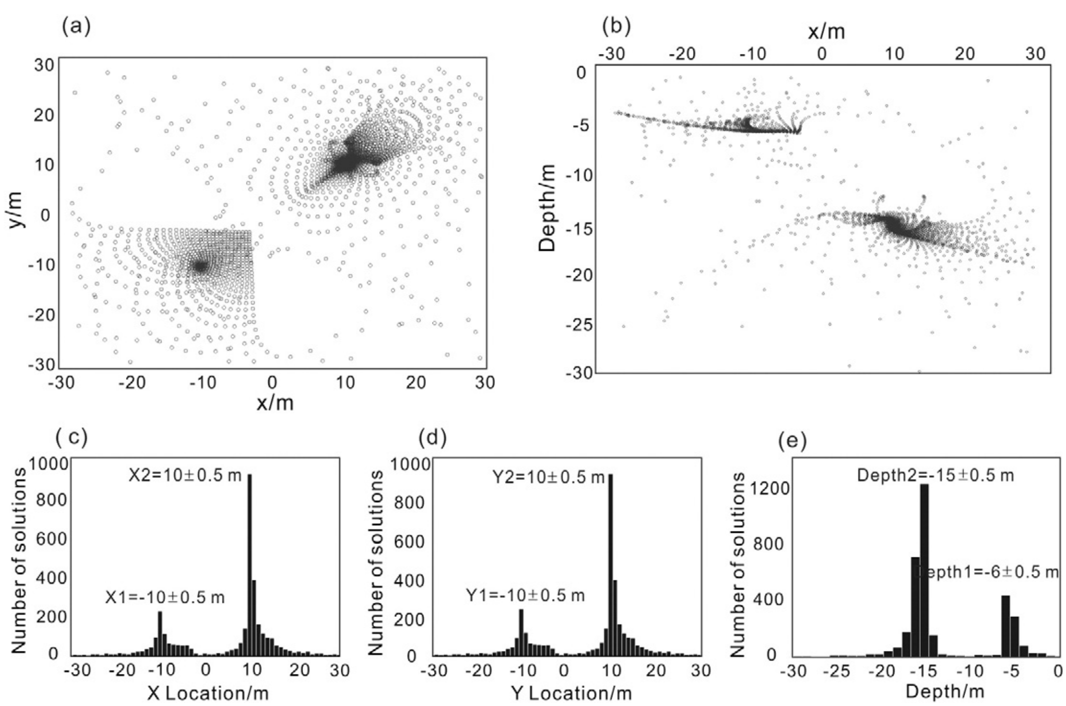


**Fig. 1.** Inversion results of a combined model with two spheres without noise. (a) Scatter diagram of the calculated horizontal position; (b) scatter diagram of the calculated depth; (c) histogram of X location; (d) histogram of Y location; (e) histogram of estimated depth.