The removal of additional edges in the edge detection of potential field data

Guoqing Ma *, Cai Liu, Danian Huang

College of Geoexploration Science and Technology, Jilin University, Changchun, 130021, China

A R T I C L E   I N F O

Article history:
Received 15 December 2014
Received in revised form 15 January 2015
Accepted 16 January 2015
Available online 19 January 2015

Keywords:
Edge detection
Additional
Potential field
Derivative

A B S T R A C T

Edge detection results of potential field data are used to delineate the horizontal locations of the causative sources, and there are many edge detection filters to finish this work. However, most of balanced edge detection filters produce additional edges which interpret the potential field data that contain positive and negative anomalies. First, we test the application effect of several common balanced edge detection filters, and then analyze the reason that produces additional edges. We present several new edge detection filters depending on the distribution features of different derivatives that will not produce additional edges. The new filters are demonstrated on synthetic gravity anomalies, which show the edges more precisely, and are insensitive to noise. We also apply them to real potential field data because they display the locations of the stratigraphic markers more precisely and clearly.

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1. Introduction

Many edge detection filters are presented to recognize the source edges; most of them are the functions of horizontal and vertical derivatives of potential field data. Initially, people (Evjen, 1936; Thurston and Smith, 1997; Cordell and Grauch, 1985; Nabighian, 1984; Roest et al., 1992) directly use the total horizontal derivative, vertical derivative and the sum of them to finish the edge detection task, but they cannot show the edges of the deeper bodies clearly. Sertcelik and Kafadar (2012) used the eigenvalues of the two-dimensional structure tensor to divide the lineaments of the subsurface, but this method cannot also display the edges of the deeper sources clearly. Some people began to study the balanced edge detection filters. Miller and Singh (1994) presented tilt angle filter that is the arc tangent of the ratio of vertical derivative to the total horizontal derivative, which can balance the amplitudes of the anomalies generated by shallow and deep bodies, but this method cannot highlight the edges of the sources clearly. Hsu et al. (1996) generalized the analytic-signal method to higher-order derivatives to increase the resolving power of this method. Verduzco et al. (2004) suggested the use of the total horizontal derivative of the tilt angle to accomplish this work where its maxima can automatically delineate the edges of geological body. The Theta map (Wijns et al., 2005) used the analytic signal to normalize the total horizontal derivative as an edge detection tool, and also use the maxima to identify the edges. Cooper and Cowan (2006) summarized the application effect of different balanced edge detection filters and proposed the normalized directional tilt angle (TDX) filter to detect the source edges. More recently, Cooper and Cowan (2008) proposed an alternative method based on the ratio of related normalized standard deviation to enhance the edges.

In our research, we find that the existing balanced edge detection filters produce additional edges in the edge detection of potential field data with positive and negative anomalies. We suggest three new balanced edge detection filters to finish the edge detection task because they will not produce additional edges, and in which the recognized edges are clearer. We also apply them to real potential field data because they can display the edges of the stratigraphic markers more precisely and clearly.

2. Methodologies

Firstly, we show the application effect of different edge detection filters. Fig. 1a shows the original gravity anomaly generated by the sources with depths of 10 and 15 m, respectively, and their densities are +1 and −1 g/cm³. The white dotted lines express the horizontal locations of the sources. Fig. 1b shows the horizontal derivative of the data in Fig. 1a, and we can see that the maxima of the data are corresponding to the edges of the sources, but it cannot show the edges of the deeper bodies very clearly. Fig. 1c and d shows the TDX and Theta map of the data in Fig. 1a, and their expressions are

$$\text{TDX} = \tan^{-1} \left( \frac{\sqrt{\left( \frac{\partial f}{\partial x} \right)^2 + \left( \frac{\partial f}{\partial z} \right)^2}}{\frac{\partial f}{\partial z}} \right)$$ (1)

* Corresponding author.
E-mail address: maguoqing@jlu.edu.cn (G. Ma).

http://dx.doi.org/10.1016/j.jappgeo.2015.01.007
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\[ \Theta = \frac{\sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 + \left(\frac{\partial f}{\partial z}\right)^2}}{\sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 + \left(\frac{\partial f}{\partial z}\right)^2}} \]  

(2)
The total horizontal derivative (BTHD), normalized analytic signal (NAS) and balanced eigenvalue of structure tensor (BE), respectively. Balanced total horizontal derivative (BTHD) can be expressed as

\[ BTHD = \tan^{-1}\left( \frac{\partial \text{THD}}{\sqrt{\left(\frac{\partial \text{THD}}{\partial x}\right)^2 + \left(\frac{\partial \text{THD}}{\partial y}\right)^2}} \right) \]  

(3)

The normalized analytic signal (NAS) can be expressed as

\[ NAS = \tan^{-1}\left( \frac{\partial \text{AS}}{\sqrt{\left(\frac{\partial \text{AS}}{\partial x}\right)^2 + \left(\frac{\partial \text{AS}}{\partial y}\right)^2}} \right) \]  

(4)

where, \( \text{AS} \) is the analytic signal of potential field data, \( \text{AS} = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 + \left(\frac{\partial f}{\partial z}\right)^2} \).

The expression of balanced eigenvalue of structure tensor (BE) is

\[ BE = \tan^{-1}\left( \frac{\partial \lambda}{\sqrt{\left(\frac{\partial \lambda}{\partial x}\right)^2 + \left(\frac{\partial \lambda}{\partial y}\right)^2}} \right) \]  

(5)

where, \( \lambda \) is one of the eigenvalues of structure tensor. The structure tensor (Weickert, 1999) is

\[ T_\alpha = G_\alpha \ast T = \begin{bmatrix} G_\alpha \ast \left(\frac{\partial f}{\partial x}\right)^2 & G_\alpha \ast \frac{\partial f}{\partial x} \frac{\partial f}{\partial y} \\ G_\alpha \ast \frac{\partial f}{\partial x} \frac{\partial f}{\partial y} & G_\alpha \ast \left(\frac{\partial f}{\partial y}\right)^2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \]  

(6)

where, \( G_\alpha \) is the function of the Gaussian envelope, which is mainly used to suppress the noise and highlight the corner information, and can be given by

\[ G_\alpha = \frac{1}{2\pi\sigma^2} e^{-\frac{1}{2\sigma^2}\left(\frac{x^2}{\sigma^2} + \frac{y^2}{\sigma^2}\right)} \]  

(7)

where, \( \sigma \) is the standard deviations of Gaussian envelope, and usually is 1 for edge detection (Sertcelik and Kafadar, 2012). The eigenvalues of
matrix is $\lambda$ and $\lambda_1$. $\lambda_1$ can show the corners of the sources, and $\lambda$ is mainly used to recognize edges. The expression of $\lambda$ is

$$
\lambda = \frac{1}{2} \left( g_{11} + g_{22} + \sqrt{(g_{11} - g_{22})^2 + 4g_{12}g_{21}} \right).
$$

Fig. 1e and f shows the balanced total horizontal derivative (BTHD) and normalized analytic signal (NAS) of the data in Fig. 1a, and the recognized edges are consistent with the real horizontal locations and do not have additional edges. Fig. 1g shows the eigenvalue $\lambda$ of the data in Fig. 1a, and Fig. 1h shows the balanced eigenvalue (BE) of the data, and the BE can show the edges of the sources clearly. We can see that new edge detection filters can display the edges of the sources more precisely.

3. Tests on synthetic gravity anomalies

We will test the application effect of the proposed filters on noise-corrupted gravity anomaly. Fig. 3a shows the data in Fig. 1a by adding random noise with mean square error (MSE) of 0.15 mGal. Fig. 3b shows the total horizontal derivative of the data in Fig. 3a. Fig. 3c and d shows the BTHD and NAS of the data in Fig. 3a; the recognized edges can delineate the horizontal locations of the sources precisely. Fig. 3f and h shows the eigenvalue and BE of the data in Fig. 3a, wherein BE obtained clearer edges. Depending on the above results we can conclude that the new edge detection filters can obtain more accurate edges, and are insensitive to noise.

We demonstrate the new filters on another format of geophysical data. Fig. 4a shows the synthetic gravity anomaly of two prisms with depths of 10 and 15 m, and their densities are both +1 g/cm$^3$. The total horizontal derivative of the data is shown in Fig. 4b where the edges of deeper bodies are blurred. The Theta map and TDX of the data in Fig. 4a are shown in Fig. 4c and d, which identified the edges of the sources clearly and do not produce additional edges for this type of data. Fig. 4e and f shows the BTHD and NAS of the data in Fig. 4a, and Fig. 4g and h shows the eigenvalue and BE of the data. Depending on the results we can see that the edges recognized by TDX and Theta map filters are more diffused than the edges identified by the new methods.

![Fig. 3. (a) Gravity anomaly in Fig. 1a by adding random noise. (b) Total horizontal derivative of the data in panel a. (c) TDX of the data in panel a. (d) Theta map of the data in panel a. (e) Balanced total horizontal derivative of the data in panel a. (f) Normalized analytic signal of the data in panel a. (g) The eigenvalue $\lambda$ of the data in panel a. (h) Balanced eigenvalue of the data in panel a.](image-url)
4. Application to real potential field data

We apply the new filters to measure gravity anomaly, and Fig. 5a shows the original gravity data of Sanjiang area, Northeast of China. The data is dominated by the near linear anomalies caused by approximately SE–NW trending structures. Fig. 5b shows the THD of the data in Fig. 5a, and the edges of the stratigraphic markers given by this method are not very clear.

The edges recognized by the TDX filter and Theta map are shown in Fig. 5c and d, and the edges are clear. Fig. 5e–f shows the BTHD, NAS, eigenvalue and BE of the data in Fig. 5a. We can see that the new filters can also show the locations of the stratigraphic markers clearly.

5. Conclusions

Edge detection results of potential field data can provide the location information of causative source. In our research, we find that the existing balanced edge detection filters produce additional edges in the edge detection of the data with positive and negative anomalies. In order to avoid the additional edges, we presented three new edge detection filters, and they use the functions of total horizontal derivative, analytic signal and eigenvalue to identify the source edges. We demonstrate the new methods on synthetic gravity anomalies which can recognize the source edges more clearly and precisely and do not produce additional edges. We also apply them to real data, and obtain the edges of stratigraphic markers clearly.

Acknowledgment

We acknowledge the assistance of the associate editors and the reviewers in improving the paper. This work is supported by the National Natural Science Foundation of China (Grant No. 41404089), State Key Program of National Natural Science of China (Grant No. 41430322) and China Postdoctoral Science Foundation (Grant No. 2014M550173).
Fig. 5. (a) Measured gravity anomaly of Sanjiang area, Northeast of China. (b) THD of the data in panel a. (c) TDX of the data in panel a. (d) Theta map of the data in panel a. (e) Balanced total horizontal derivative of the data in panel a. (f) Normalized analytic signal of the data in panel a. (g) The eigenvalue $\lambda$ of the data in panel a. (h) Balanced eigenvalue of the data in panel a.

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