Application of image processing methods in edge detection of potential field data

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SUMMARY

On the basis of conventional methods for edge detection on potential field data, various source edge enhancement techniques have been studied to improve signal-to-noise ratio and localization accuracy. However, problems such as low resolution, noise interference and false edge information still exist. In this paper, three image processing methods are introduced, which use the Canny, LoG and Sobel operators. We describe briefly the principle of the methods and apply them to edge detection of geological bodies. As well, three typical numerical calculation methods of edge detection are selected and compared with image processing methods on edge detection effect. The results show that image processing methods can effectively identify the edge of geological bodies, especially for the Canny operator, which can prevent the introduction of errors and is insensitive to noise. To verify the practical application effect of these image processing methods, magnetic anomaly data from the Zhurihe area in China are processed in this paper. The results indicate that the Canny operator is capable of detecting the edge position of geological bodies in the study area more clearly, and that the edges corresponds to known information. Therefore, image processing methods can be used in edge detection and that satisfactory practical application can be achieved.

Key words: edge detection; image processing; potential field data; numerical calculation.

INTRODUCTION

Edge detection is indispensable in processing potential field data. The principle is to determine the position and expansion of sources in the horizontal plane based on distinct density or magnetic difference along edge areas. The commonly used methods can be summarized as numerical methods and statistical methods, with the numerical methods including vertical derivative, total horizontal derivative, analytic signal amplitude (ASM), tilt angle (Tilt) and theta map (Theta), etc. Therein, ASM was proposed by Nabighian (1972) and this method is not sensitive to magnetic anomaly components and the magnetization direction, and has relatively low resolution. Miller and Singh (1994) presented the first balanced filter--- tilt angle. However, it can only detect edges effectively when the contact zone has an angle of 0 or 90 degrees. Wijins *et al.* (2005) proposed a new method--- theta map which could balance gravity and magnetic data with high and low amplitudes, but analytic singularities might exist in the results. Numerical methods are easy to implement and the computation is fast, but the calculation of derivatives will amplify noise and wrong information would be introduced when both positive and negative anomalies exist. To solve the problems, we proposed three prevailing image processing methods in this paper.

When processing images, edge enhancement is of vital importance for extracting features. With the development of image processing techniques, these edge enhancement methods have been used in many domains. Liu (2016) applied differential, LoG (Laplacian-of-Gaussian) and Canny operators into extracting geological boundaries and obtained satisfactory results. Yang (2015) utilized the Canny operator in edge detection of gravity and magnetic anomalies. Edges and noisy points are distinguished effectively and the result is acceptable. On the basis of investigation into the pertinent literatures, we would use Canny, LoG and Sobel operators in edge detection. At the same time, the above three numerical methods are applied to draw a comparison. Gravity model data and real gravity and magnetic data are studied in the application part. The results show the proposed image processing methods could overcome the difficulties in using numerical methods and better edge detection is achieved.

METHOD AND RESULTS

Numerical Methods

A brief introduction to three numerical edge detection methods is given in this part. ASM is the module of total derivatives along three directions of the potential field data. Its expression is

$$ASM = \sqrt{\left(\frac{\partial V}{\partial x}\right)^2 + \left(\frac{\partial V}{\partial y}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2}, \qquad (1)$$

where V denotes potential field. Tilt angle refers to the ratio of vertical derivative over horizontal derivative and the formula is

$$Tilt = \arctan\left(\frac{\partial V/\partial z}{(\partial V/\partial x)^2 + (\partial V/\partial y)^2}\right), \tag{2}$$

Theta map calculates the cosine of the angle between the analytic signal vector and the horizontal plane. It is written as

$$\cos(\theta) = \frac{\sqrt{(\partial V/\partial x)^2 + (\partial V/\partial y)^2}}{\sqrt{(\partial V/\partial x)^2 + (\partial V/\partial y)^2 + (\partial V/\partial z)^2}}, \tag{3}$$

Image processing methods

Four steps are included in the Canny algorithm:

1) Filtering

The original data is convolved with a 2D Gaussian filter and a smoothed result is obtained. Given a function $f(x,y)$, the convolution result is

$$\begin{aligned} g(x,y) &= G(x,y;\sigma) * f(x,y) \\ &= \sum_{k=0}^{x-1}\sum_{l=0}^{y-1} g(k,l;\sigma) f(x-k, y-l), \end{aligned} \tag{4}$$

where $G(x,y;\sigma) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$ is the function of Gaussian filter and standard deviation σ determines smooth level.

2) Calculating amplitude and direction of the gradient

The amplitude and direction of the gradient of any data point in the data matrix are defined as

$$\left.\begin{aligned} M(x,y) &= \sqrt{\left(\frac{\partial g(x,y)}{\partial x}\right)^2 + \left(\frac{\partial g(x,y)}{\partial y}\right)^2} \\ \theta(x,y) &= \arctan\left(\frac{\partial g(x,y)}{\partial y} \Big/ \frac{\partial g(x,y)}{\partial x}\right) \end{aligned}\right\}, \tag{5}$$

Amplitude M reflects the edge intensity of the data and θ shows direction of the edges.

3) Suppressing the non-maxima

Approximating the gradient direction of each data point as any from [0, 45, 90, 135, 180, 225, 270, 315], and comparing the gradient intensity between this point and points along the above direction. Setting its value to zero if it is smaller than any other point.

4) Detecting and connecting edges with dual-threshold

In Canny algorithm, dual-threshold is used to remove noise after suppressing the non-maxima. Eshaghzadeh and Salehyan (2016) proposed the empirical equation of the upper bound of the optimal threshold as

$$T_{upper} = \sqrt{\frac{|S_M - A_M|}{Max_M}}, \tag{6}$$

where S_M, A_M and Max_M denote standard deviation, average and maximum of the gradient intensity, respectively.

LoG operator processes the original data with the Gaussian filter firstly and calculates the second order derivative. Zero crossings of the result show the position of the edges. Different from Canny algorithm, LoG calculates the derivatives first and then convolves the results. Using the same Gaussian filter as in Eq.(4), we have the Gaussian kernel function in convolution as

$$\begin{aligned} LoG &= \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) G(x,y;\sigma) \\ &= \frac{1}{\sigma^2}\left(\frac{x^2+y^2}{\sigma^2} - 2\right) e^{\frac{-(x^2+y^2)}{2\sigma^2}}, \end{aligned} \tag{7}$$

It is also essential to threshold the zero crossings in order to suppress noise.

The Sobel operator detects edges along vertical and horizontal directions at the same time and that can be written as a weighting matrix as

$W_x = [-1\ 0\ 1;\ -2\ 0\ 2;\ -1\ 0\ 1]$ and $W_y = [1\ 2\ 1;\ 0\ 0\ 0;\ -1\ -2\ -1]$. Convolving the original data D and W, the intensity difference along vertical and horizontal direction is obtained and written as

$$\left.\begin{aligned} S_x &= W_x * D \\ S_y &= W_y * D \end{aligned}\right\}, \tag{8}$$

The approximation of gradient and direction of each data point is

$$\left.\begin{aligned} M(x,y) &= \sqrt{S_x^2 + S_y^2} \\ \theta(x,y) &= \arctan\frac{S_x}{S_y} \end{aligned}\right\}, \tag{9}$$

The next step is the same as step 4) of the Canny operator.

Results of application

To verify the edge detection effect of the proposed methods, we apply the three methods to real magnetic data acquired in the Zhurihe area in China. The original magnetic data was reduced-to-pole. The Canny, LoG, and Sobel operators and three numerical methods are used on the model data, and the edge detection results are shown in Figure 1. The magnetic anomaly is shown in Figure 1(a). It is possible to see the distribution of anomalous sources. From the results, we can see that the three operators roughly depict the range of the metallogenic zone, which matches well with magnetic anomaly in Figure 1(a). Furthermore, compared with the numerical methods, the results of the Canny, LoG and Sobel operators show more convergence and are less susceptible to noise, especially the Canny operator. In Figure 1(e)-(g), ASM gives a result with low resolution, Tilt and Theta amplify noise and thus produce fake edge points. LoG and Sobel operators could draw a clear edge position, but wrong information is also introduced. The Canny operator shows a better result, which is in accordance with known information (Ma *et al*., 2012).

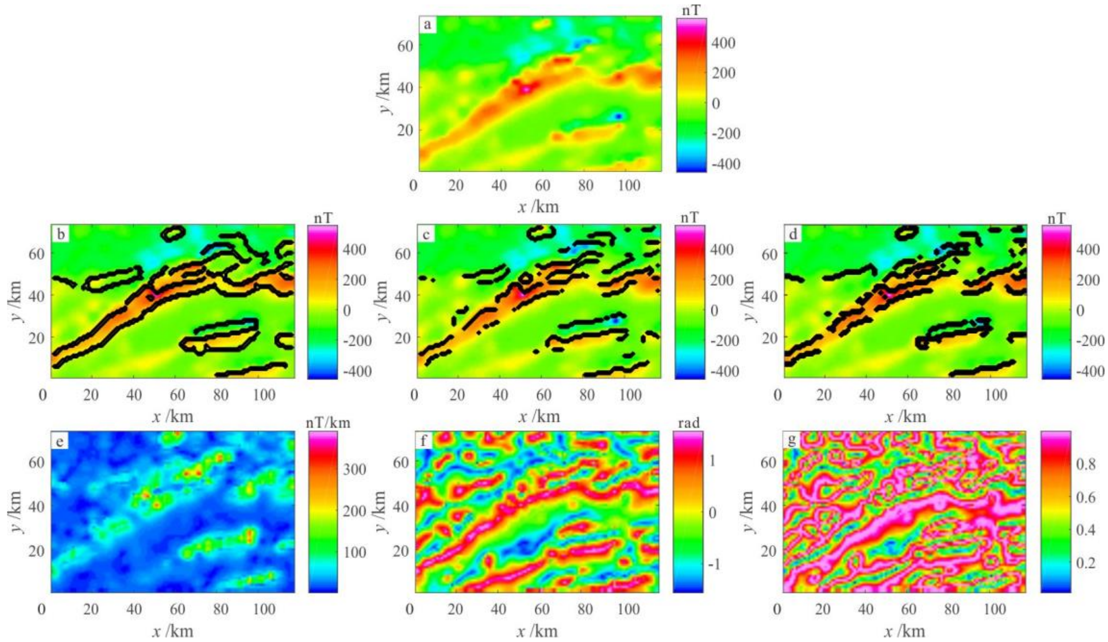

Figure 1: Edge detection results of magnetic anomaly of Zhurihe region
(a) magnetic anomaly after reduction to pole, (b) edge detection of Canny, (c) edge detection of LoG, (d) edge detection of Sobel, (e)edge detection of ASM, (f) edge detection of tilt angle, (g) edge detection of theta map, the black points denote edge positions detected by the three operators.

CONCLUSIONS

In order to overcome problem such as noise interference and wrong information introduction of conventional numerical methods, image processing methods are proposed in this paper. Three edge detection operators are described and applied to real magnetic data, and the results show that satisfactory application effect is achieved. When using numerical methods, it is difficult to obtain high resolution and low noise level at the same time. The three operators we use would suppress noise in advance and the results show more accurate edge positions. The operators calculate the intensity and direction of horizontal gradient as well as use extreme or zero points to locate edges. Therefore, the edge detection effect is better for potential field anomalies with more horizontal distribution. For LoG and Sobel operators, it is also obvious that noisy points have a scattered distribution and might cause misfit of real position of edges. So there is still potential to improve the methods on suppressing noise.

ACKNOWLEDGMENTS

This work was supported by National Oil and Gas Major Project Sub-task (2016ZX05027-002-003).

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