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Application of edge detection to potential field data using eigenvalue analysis of structure tensor

I. Sertcelik [a], O. Kafadar [b,*]

[a] Kocaeli University, Engineering Faculty, Dept. of Geophysical Engineering, 41380 Kocaeli, Turkey
[b] Kocaeli University, Dept. of Computer Programming, 41135 Kocaeli, Turkey

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ABSTRACT

One of the most important aims of potential field geophysicists is delineate the edges of subsurface structures. There are many methods based on horizontal and vertical derivative of potential field data for edge detection and enhancement. The structure tensor technique one of the image processing techniques is used to edge detection studies in many scientific areas. In this paper, the technique was applied to potential field data and detected edges of the subsurface lineaments using its eigenvalue analysis. Based on noise-free and noisy synthetic data sets, the technique was tested and satisfactory results were obtained. The proposed method was applied on two real potential field data which are gravity data of Konya region and magnetic data of Eastern Anatolia Region in Turkey. These examples demonstrate that the technique provides beneficial information to geoscientists for determining the horizontal location of subsurface structures such as contacts, faults or various source bodies.

1. Introduction

Edge detection and edge enhancement techniques provide important knowledge to potential field geophysicists to interpret the potential field data. For this purpose, many techniques have been developed by various authors (Blakely and Simpson, 1986; Mallat and Zhong, 1992; Trompat et al., 2003). Most of these techniques are based on horizontal and vertical derivatives of potential field data (Aydogan, 2011; Cooper and Cowan, 2008; Cordell, 1979; Cordell and Grauch, 1985; Miller and Singh, 1994; Veduzco et al., 2004). Cordell and Grauch (1985) developed a method for the location of the horizontal extents of the source bodies from the maxima of the horizontal gradient of the pseudogravity computed from the magnetic data. Then Blakely and Simpson (1986) improved the technique using curve-fitting approach. There are advantages and disadvantages of derivative-based edge detection methods. Aim of the derivative-based methods is to clarify the eligibility of the anomalies while strengthening the high-frequency components in the anomalies. During this process, the noise in the anomaly will be also strengthening in addition to high-frequency components.

The numerous edge detection and enhancement techniques used in image processing are suitable for the analyzing potential field data. Recently, some of the image processing techniques such as wavelet analysis (Fedi and Quata, 1998), Markov Random Field (Albora et al., 2007a, 2007b) and Cellular Neural Network (Aydogan, 2007; Aydogan et al., 2005) have been applied to geophysical data for edge detection, edge enhancement and separation of potential field anomalies. The structure tensor is also one of the image processing techniques and represents a local orientation in an n-dimensional space.

First, the method was used by Förstner (1986) and Harris and Stevens (1988) for low-level feature analysis. The method gained popularity for corner detection (Rohr, 1994). Later it was applied for edge detection (Förstner, 1994), texture analysis (Rao and Schunck, 1991) and optic flow (Nagel and Gehrke, 1998). In geophysics, the method was used by Jeong et al. (2006) to detect faults using the 3D seismic images.

In this study, the structure tensor technique was applied on potential field data. The edges and corners of causative bodies were extracted using its eigenvalues. In contrast to traditional derivative-based methods, the structure tensor has a property which reduced noise in the data while enhancing discontinuity boundaries. We conclude that the eigenvalues of the structure tensor provide us important knowledge about edges and corners of subsurface structures.

2. Theory of structure tensor and its eigenvalue analysis

The technique can be applied easily in the several steps. First, the Gaussian envelope $G_\sigma(x,y)$ is computed and convolved with potential field data. σ_x and σ_y are the standard deviations of Gaussian envelope in x and y directions. The process is used to smoothing the potential field data.

$$G_\sigma(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{1}{2}\left(\frac{x^2}{\sigma x^2}+\frac{y^2}{\sigma y^2}\right)}. \tag{1}$$

* Corresponding author. Tel.: +90 5372440078; fax: +90 262 3732719.
E-mail addresses: isert@kocaeli.edu.tr (I. Sertcelik), okafadar@kocaeli.edu.tr (O. Kafadar).

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The parameters M, M_σ and * are the potential field data, smoothed data and convolution operator, respectively.

$$M_\sigma(x,y) = G_\sigma(x,y) * M(x,y). \tag{2}$$

The structure tensor matrix T consists of gradients of the smoothed potential field data. In this paper, two-dimensional structure tensor is used to analysis of the potential field data. The structure tensors given by Eq. (3) are calculated using the derivatives of smoothed data in the each data points. The tensor only contains three independent components of potential field data.

$$T = \nabla M_\sigma \otimes \nabla M_\sigma = \nabla M_\sigma \nabla {M_\sigma}^T = \begin{bmatrix} \left(\frac{\partial M_\sigma}{\partial x}\right)^2 & \frac{\partial M_\sigma}{\partial x}\frac{\partial M_\sigma}{\partial y} \\ \frac{\partial M_\sigma}{\partial x}\frac{\partial M_\sigma}{\partial y} & \left(\frac{\partial M_\sigma}{\partial y}\right)^2 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}. \tag{3}$$

The matrix given by Eq. (3) is structure tensor, interest operator or second-moment matrix. The structure tensor can be demonstrated the product of three matrix given by Eq. (4) which are eigenvector matrix v, eigenvalue matrix λ and transpose matrix of eigenvector v^T.

$$T = \begin{bmatrix} v_1 & v_2 \\ v_3 & v_4 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \begin{bmatrix} v_1 & v_2 \\ v_3 & v_4 \end{bmatrix}^T. \tag{4}$$

$$\lambda^2 - \lambda(T_{11} + T_{22}) + (T_{11}T_{22} - T_{12}T_{21}) = 0. \tag{5}$$

The eigenvalues of the structure tensor can be calculated using Eq. (5). The roots of the polynom given by Eq. (5) are eigenvalues of the structure tensor. The results of analysis of eigenvalues are shown that λ_1 and λ_2 are ordered as $\lambda_1 > \lambda_2 > 0$.

3. Synthetic model experiments

In this section, the effectiveness of the structure tensor technique is tested on two synthetic total magnetic field data. We used synthetic models consist of prism bodies due to they are most appropriate models for edge and corner detection. In the first synthetic application, a synthetic total magnetic field data caused by four vertical-sided prisms at a depth to the top of 2 km (labeled 1), 3 km (labeled 2), 2 km (labeled

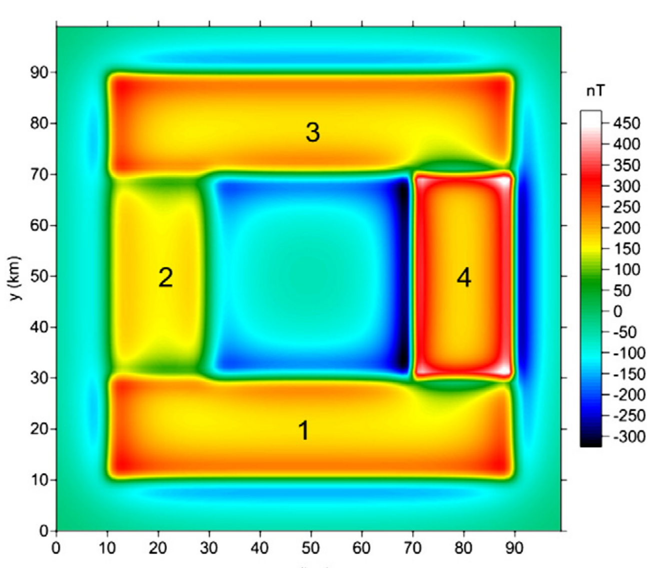

Fig. 1. Synthetic total magnetic field data set, consisting of anomalies from four vertical prism bodies with depths of 2 km (prism 1), 3 km (prism 2), 2 km (prism 3) and 1 km (prism 4) for magnetization vector at 90° and magnetization strength of 470 A/m.

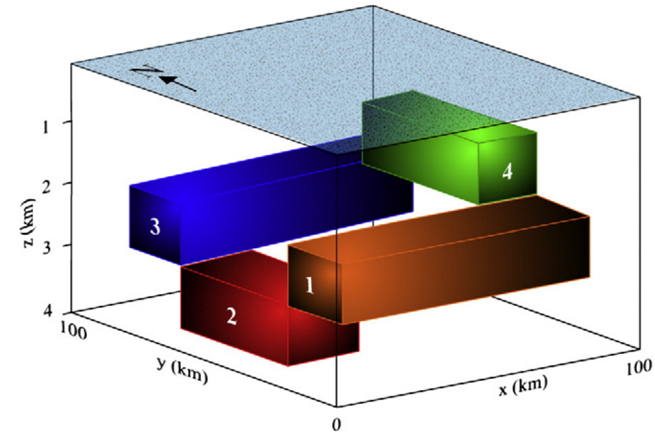

Fig. 2. 3D view of synthetic model (1).

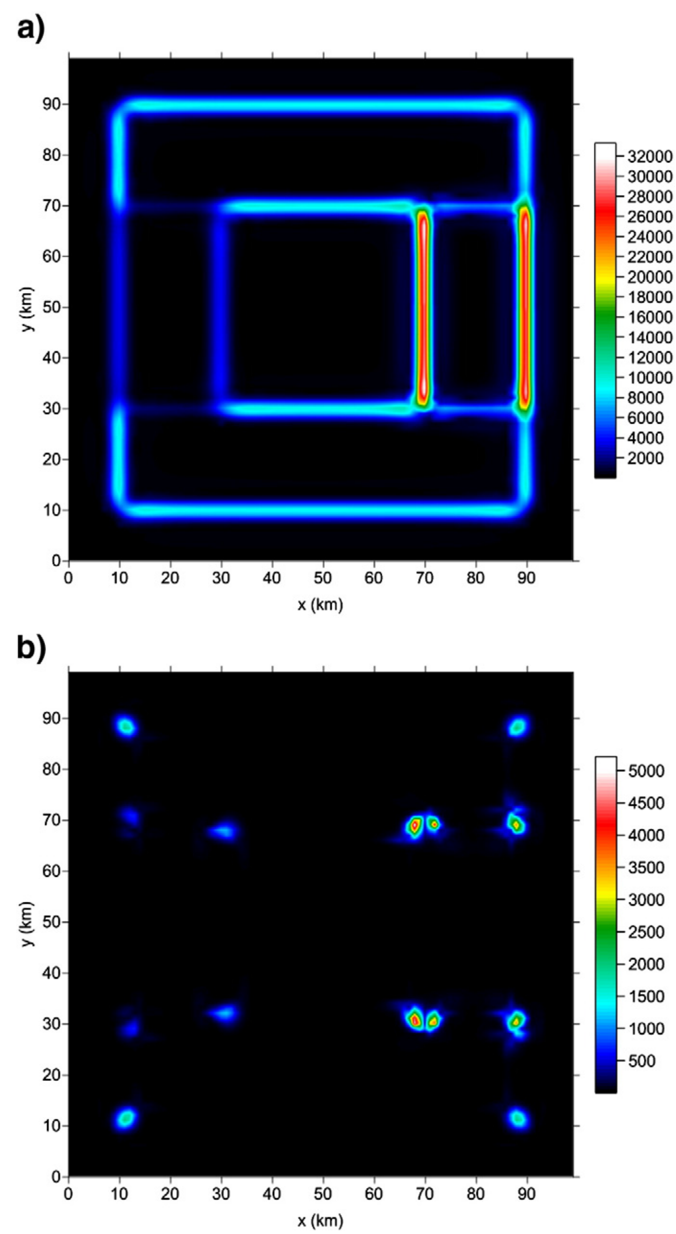

Fig. 3. Eigenvalue maps obtained from total magnetic field data in Fig. 1. a) Largest eigenvalue map, b) smallest eigenvalue map.