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Research Article

Edge detection of gravity anomaly sources via the tilt angle, total horizontal derivative, total horizontal derivative of the tilt angle and new normalized total horizontal derivative

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Abstract: In this paper the application of edge detection techniques to gravity data are described. Edge enhancement in potential-field data helps geologic interpretation. There exist several methods for enhancing edges, such as tilt angle, and the derivative of tilt angle. Most of these methods are high-pass filters based on the horizontal or vertical derivatives of the field. To determine the filters new normalized total horizontal derivative (NNTHD), normalized horizontal derivative (NTHD), total horizontal derivative (TDX) and tilt angle as an edge detector (THDR), a computer code in Matlab was prepared. The filter has been tested by comparison with related high-pass filters with synthetic data and measured data; it gives outstanding results for the data sets employed for which the NNTHD method can make large and small amplitudes of source edges equally visible, with more detail wherever the data are relatively smooth. NNTHD, a new edge-detection filter, is based on ratios of horizontal derivative to the mean of the nearby horizontal derivatives. Compared with other filters, the NNTHD filter produces more detailed results. The advantage of the NNTHD method in the recognition of source edges is due to the fact that it can make the strong and weak amplitude edges visible simultaneously, and can bring out more details. The advantage of the NNTHD method is most obvious in the regions where the data are relatively smooth. As the standard deviation of this method (0.1784) is greater than the NTHD method (0.0710), this method displays the gravity anomalies more clearly than the NTHD.
Keywords: Gravity gradient, Tilt angle, Edge detection, New normalized horizontal derivative

INTRODUCTION

There exist several types of high pass filters which enhance subtle detail in potential field data, such as downward continuation, horizontal and vertical derivatives. The horizontal location of the edges of causative sources is a commonly requested task in the interpretation of geophysical data; many filters are available to accomplish this task. The vertical

Derivative has been used for many years to delineate edges in gravity and magnetic field data[1-3The authors have commented on the utility of the horizontal and vertical magnetic gradients for delineating the edge of a body that has vertical sides. Grauch and Cordell [4] have investigated the effect of a sloping side on the location of the maximum horizontal gradient. Telford et al. [5] explained that the location of the maximum horizontal gradient may be used as an indicator of the location of the edges of the source. In general, the first vertical derivative is positive over the source, zero over the edge and negative outside of a vertical sided source. The horizontal gradient peaks over the edges and is zero over the body. Thus, either of these two measures will locate the edges of an isolated anomaly source, similar to the analytical signal of Roest et al. [6]. Other authors have advocated use of second vertical derivative for locating the edges[7]. However, even with the second derivative, the zero value is not located exactly over the edge. It is noteworthy that in all of above-mentioned methods, if there exist more than one source of anomaly, the resolution will also varies. Shallower sources are well resolved, but the deeper ones with shallower gradients may not be as apparent because the effective measure is the gradient amplitude. There may be a considerable dynamic range in the size of the gradients, implying that profiles or maps cannot provide enough signal to be detected.

The tilt angle overcomes this problem by dealing with the ratio of the vertical derivative to the horizontal gradient. As both will be smaller for deeper sources, the ratio will be large over the source. It becomes zero over or near the edge where the vertical derivative is zero and the horizontal gradient is maximum, while becomes negative outside the body where the vertical derivative is negative. By expressing this as a tilt angle rather than a ratio, it will always be in the range of -90°< TILT< 90°. The tilt angle is relatively insensitive to the depth of the source and should resolve shallow and deep sources equally. Miller and Singh[8] introduced the tilt angle, an amplitude normalized vertical derivative:

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

where *f* is the magnetic or gravity field.

As one can observe from equation (1), the tilt angle enhances large and small amplitudes of anomalies well. This is due to the fact that, the tilt angle is determined based on the ratio of the total horizontal derivative to the vertical derivative. It is to be noted that, the tilt angle is positive over the source of anomaly and passes through zero when it places over or near the edge of anomaly.

It is effective in balancing the amplitude of strong and weak anomalies, but it is not primarily an edge-detection method[9].

A commonly used edge-detection filter is the total horizontal derivative (TDX),

$$TDX = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \qquad (2)$$

Verduzco et al. [10] suggest using the total horizontal derivative of the tilt angle as an edge detector (THDR):

$$THDR = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad (3)$$

The THDR successfully delineates the edges of the largest amplitude anomaly, but its results for the deeper bodies are less impressive. Because the THDR uses derivatives of a derivative-based filter, i.e., the tilt angle, it can also enhance noise in the data.

In this paper, we present edge-detection filter using the normalized total horizontal derivative (NTHD) to delineate the edges of sources.

Ma and Li [11] introduced the normalized horizontal derivative (NTHD):

$$NTHD(i,j) = \frac{TDX(i,j)}{\max[TDX(i-m:i+m,\, j-n:j+n]} \qquad (4)$$

The normalized total horizontal derivative (NTHD) is the ratio of the horizontal derivative to the maxima of nearby horizontal derivatives. The new normalized total horizontal derivative (NNTHD) is the ratio of the horizontal derivative to the mean of nearby horizontal derivatives. This method does not require the computation of the vertical derivative, making the filter computationally more stable. It can be expressed as:

$$NNTHD(i,j) = \frac{TDX(i,j)}{mean[TDX(i-m:i+m,\, j-n:j+n]} \qquad (5)$$

Where $NNTHD(i, j)$ represents the output value of (i, j), TDX represents the total horizontal derivatives and *m* and *n* both are the size of window (i.e., the size of the sample). Horizontal derivative, tilt angle and the total horizontal derivative of the tilt angle is a widely used method.

The total horizontal derivatives and the total horizontal derivative of the tilt angle can also automatically recognize edges in potential field data via their maxima, while the tilt angle can be used to verify the existence of weak anomalies. From expression (5), we can see that the size of the window influences the results. In the process of delineating edges in potential field data, we can first test the effect of different windows, and then select the best results.

SYNTHETIC GRAVITY ANOMALY

In order to test the feasibility of the NNTHD method, we choose four other similar methods to compare results. They include the tilt angle (equation 1), total horizontal derivative equation 2), total horizontal derivative of the tilt angle equation 3) and the normalized horizontal derivative (NHD) (equation 4). Figure 2a shows the gravity anomaly generated by two identical prisms at central depths of 5 and 10 m (Figure 1). The total horizontal derivative of Figure 2a is shown in Figure 2b. The edges of sources have been enhanced, but unfortunately the edges of the deeper body cannot be recognized clearly. The tilt angle of Figure 2a is shown in Figure 2c. Although the tilt angle is a valid method in balancing the amplitudes of different anomalies, it is not mainly an edge-detection filter. The THDR of Figure2a is shown in Figure 2d. The THDR can delineate the edges of the shallower source successfully, although the edges of the deeper body are rather vague. The NTHD results of Figure 2a with different windows are shown in Figs. 3a-b. The NNTHD results of Figure 2a with different windows are shown in Figs. 3c-d. The NNTHD method displays the edges of the shallow and deep sources more clearly and improves the resolution power of the body's lateral location.

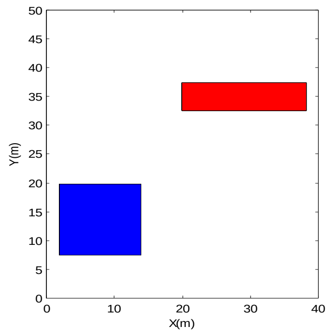

Fig-1:**Two identical sources at different depths.**

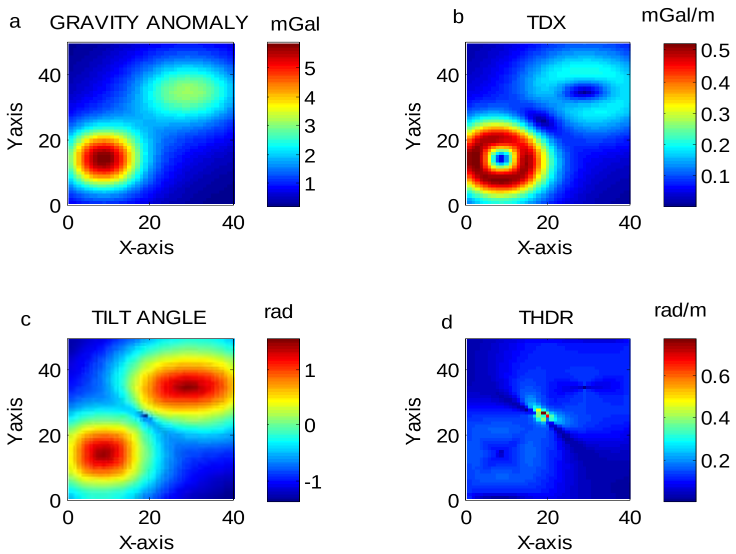

Fig-2: **(a) Synthetic gravity anomaly field generated by two identical sources at different depths. (b) Total horizontal derivative of the data in (a) computed using Eq. 2. (c) Tilt angle of the data in (a), computed using Eq. 1. (d) THDR of the data in (a), computed using Eq. 3.**

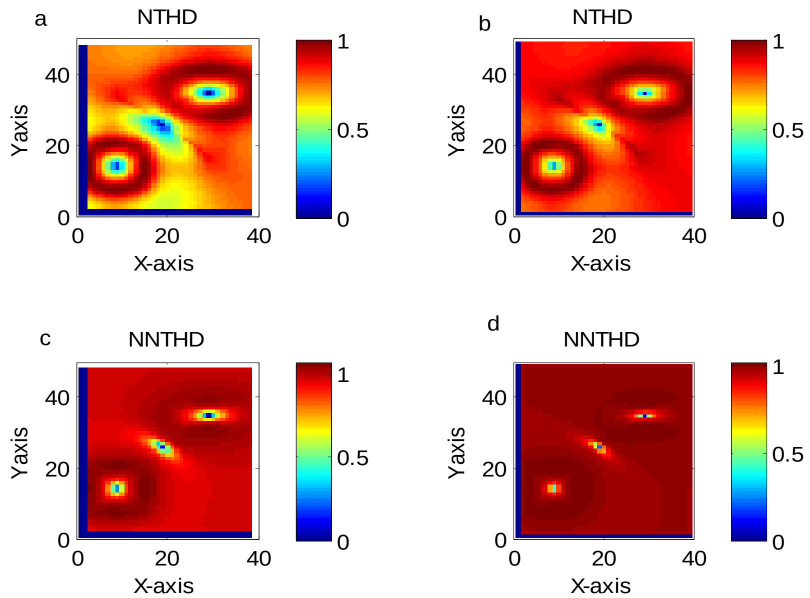

Fig-3: (a) NTHD of the data in Figure 2a, computed using Eq. 4 with a window size of 5 x 5. (b) NTHD of the data in Figure 2 a, computed using Eq. 4 with a window size of 3 x 3 (c) NNTHD of the data in Figure 2a, computed using Eq. 5 with a window size of 5 x 5. (d) NNTHD of the data in Figure 2 a, computed using Eq. 5 with a window size of 3 x 3.

APPLICATION OF REAL GRAVITY ANOMALIES

The present investigation concerns the gravity dataset in order to enhance edges structure from gravity data. Figure 4a shows a gravity map of southwest Iran and north of the Oman Sea, displaying intense high gravity with the east-vest (EW) trends, corresponding to Prism sedimentary Makran, while Figure 4b-d shows the TDX, tilt angle and THDR of the data in Figure 4a. According to Figures 4b-d and 5a-d, the TDX, the tilt angle and the THDR are observed with high-amplitude anomalies. As gravity data often contain anomalies with a large range in amplitude, the processed gravity images such as TDX, tilt angle, THDR, and NTHD similarly contain features with large fluctuations in amplitude. It is possible that the smaller amplitude anomalies might be of considerable geologic interest, but they can be hard to delineate among those of larger amplitude. In Figure 4b-d and Figure 5a-d the maximum values are located over causative bodies. In other words, there is no balance between the outputs. Figure4 b-d and Figure5 a-d provides the best resolution of the gravity markers in the Oman Sea structure.

Advantage of the NNTHD method is most obvious in the regions where the data are relatively smooth. As the standard deviation of this method (0.1784) is greater than the NTHD method (0.0710), gravity anomalies are obviously better. This filter has successfully enhanced the edges of the low-amplitude sources. According to Figure 4b-d and Figure 5a-d the obtained TDX, tilt angle, THDR, NTHD and NNTHD method lineaments are consistent with each other, although NNTHD has a higher resolution. Figure 4 b-d and Figure 5 a-d, indicates the horizontal location of all sources. They are similar to the map of the second vertical derivatives which have been traditionally used to locate the edges on the sources. The NNTHD map has the advantage of detecting both shallow and deep sources, whereas the TDX, tilt angle, THDR, responds preferentially to shallower and smaller sources.

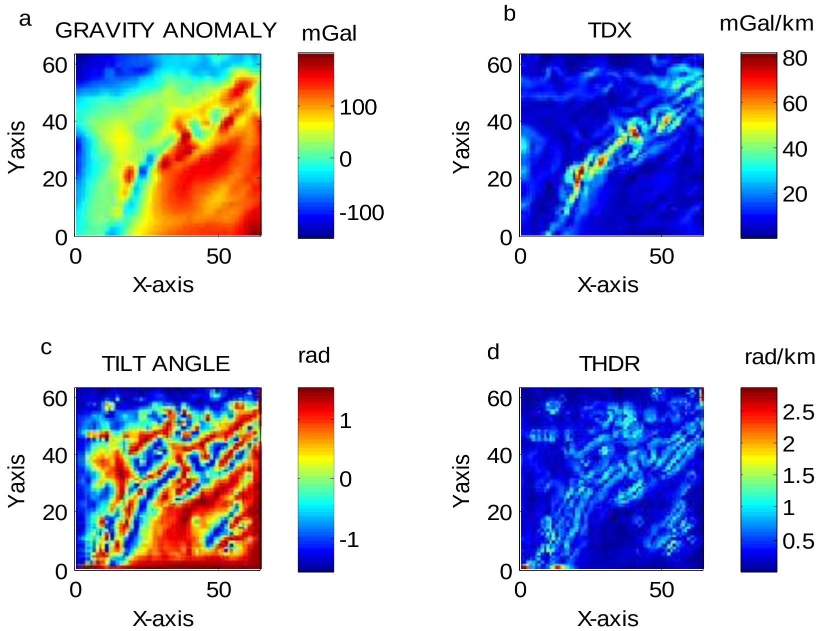

Fig-4: (a) Measured gravity data from the Oman Sea in southeastern Iran. (b) Total horizontal derivative of the data in (a) using Eq. 2. (c) Tilt angle of the data in (a) using Eq. 1. (d) THDR of the data in (a) using Eq. 3.

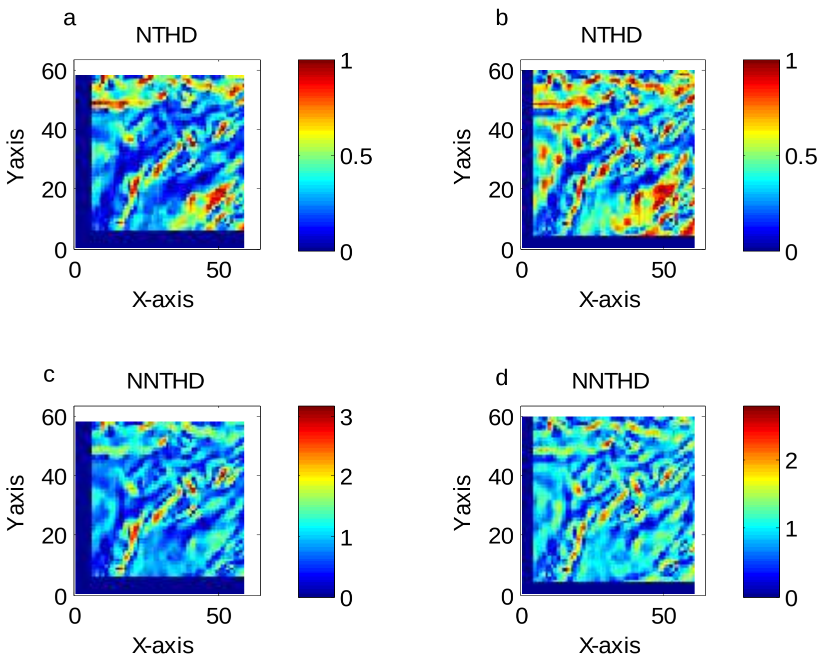

Fig-5: (a) NTHD of the data in Figure 4 a using Eq. 4 with a window size of 5 x 5. (b) NTHD of the data in Figure4 a using Eq. 4 with a window size of 3 x 3, (c) NNTHD of the data in Figure 4a using Eq. 5 with a window size of 5 x 5, (d) NNTHD of the data in Figure 4 a, using Eq. 5 with a window size of 3 x 3.

CONCLUSIONS

In spite of the last gradient methods which were used in addition to the main interpretation methods, the analysis by space plots could be used independently as the primary analysis, while there is no imagination from type of geologic structures. The apparent division is useful for quick selection of separation points; however this technique is not always credible way to withdraw the smaller anomalies. Local phase filters (NNTHD, NTHD, TDX, T and THDR) as anomaly detector edges are very strong.

The NNTHD edge-detection filter - is based on the total horizontal derivative of potential field anomalies. This method avoids the computation of vertical derivatives which makes the filter computationally more stable. To determine the filters NNTHD, NTHD, TDX, T and THDR, a computer code in MATLAB was prepared. The filter has been tested by comparison with related high-pass filters with synthetic and measured data. Results indicate that the NNTHD method can create large and small amplitudes of source edges equally visible, with more detail wherever the data are relatively smooth.

NNTHD map enables the interpreter to determine the approximate horizontal location and lateral extent of the sources for both shallow and deep condition. It may also be used with the apparent strike information to produce a stereo plot, summarizing the orientation of the potential field at all grid points on the map. This use enables the interpreter to sort out the various sources on the basis of their orientation statistics similar to the way a geologist plots orientation data to ascertain structure alignments.

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