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A NEW METHOD FOR EDGE DETECTION IN INTERPRETATION OF POTENTIAL FIELD DATA

Luan Thanh PHAM[1], Thanh Duc DO[1], Erdinc OKSUM[2*]

[1] VNU University of Science, Faculty of Physics, Dept. of Geophysics, Ha Noi, Vietnam
[2] Süleyman Demirel University, Engineering Faculty, Dept. of Geophysical Engineering, Isparta, Turkey

Keywords
Hyperbolic tangent function, Analytic signal amplitude, Edge detection.

Abstract
In magnetic interpretation, most existing edge detection filters have the disadvantages that they require a reduction to the pole or pseudo-gravity transformation as a pre-process of the magnetic data and beside this, the identified edges of deep sources are generally diffuse and fuzzy, or cannot balance the edges of strong and weak amplitude anomalies simultaneously. In order to overcome these problems, we introduce a new filter, which can improve these disadvantages effectively. The filter is based on the derivatives of the analytic signal amplitude and the hyperbolic tangent function. The feasibility of the filter is demonstrated on three cases of synthetic data caused by theoretical models in variable depths and positions. The outcomes are compared with the results of frequently used other edge detectors such as the analytical signal amplitude and the tilt angle of the analytic signal amplitude. The results show that the new filter can achieve better edge delineation.

POTANSİYEL ALAN VERİLERİNİN DEĞERLENDİRİLMESİNDE YENİ BİR YAPI SINIRI BELİRLEME YÖNTEMİ

Anahtar Kelimeler
Hiperbolik tanjant, Analitik sinyal genliği, Sınır belirleme.

Öz
Manyetik verilerin değerlendirilmesinde kullanılan mevcut sınır belirleme filtrelerinin birçoğu ön işlem olarak kutba indirgeme veya yalancı gravite dönüşümü gerektirmesi nedeniyle bir dezavantaj oluşturmaktadır. Bunun yanı sıra derin yapılara ilişkin elde edilen yapı sınırları genel olarak dağınık ve bulanık olmakta veya derin ve sığ yapılardan ileri gelen zayıf ve şiddetli anomalilerin genlik dengelemesi yapılamadığından sığ ve derin kaynakların sınırları eşzamanlı olarak belirlenememektedir. Bu çalışmada, söz konusu bu dezavantajların üstesinden gelen yeni bir sınır belirleme filtresi sunuyoruz. İşlevsel olarak bu filtre, analitik sinyal genlik türevlerine ve hiperbolik tanjant fonksiyonuna dayanmaktadır. Yöntemin etkinliği, değişken konum ve derinlikler ile temsil edilen model yapıların oluşturduğu üç farklı sentetik anomali üzerinde gösterilmiştir. Elde edilen sonuçlar, analitik sinyal genliği ve analitik sinyal genliği tilt açısı gibi sık kullanılan diğer yapı sınır belirleme yöntemlerinin sonuçlarıyla da karşılaştırılmıştır. Karşılaştırma sonuçlarına göre bu çalışma ile sunulan filtrenin diğer filtrelere göre sınırların tespitinde daha etkin olduğu gösterilmiştir.

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[*] İlgili yazar / Corresponding author: erdincoksum@sdu.edu.tr

1. Introduction

The edge detection plays an important role in magnetic interpretation. There are many filters for detecting edges of magnetic sources, most of which are based on the vertical or horizontal derivatives of the magnetic anomalies or combinations of them. One of the most popular filter is the analytical signal amplitude proposed by Nabighian (1972) and Roest et al. (1992). For the 2D case, its shape is independent of the direction of the ambient magnetic field and the direction of source magnetization, but this is not for the 3D case (Li, 2006). Hsu et al. (1996) introduced an enhanced analytic signal. Because this method based on the higher order derivatives, it is sensitive to noise. Another disadvantage of these methods is that they cannot display large and small amplitude edges simultaneously. In order to make the strong and weak amplitude edges visible simultaneously, Miller and Singh (1994) suggested using tilt angle that it defined as the arctangent of the ratio of vertical derivative to total horizontal derivative of the magnetic field. Verduzco et al. (2004) used the total horizontal derivative of tilt angle; Wijns et al. (2005) used the theta map filter that use analytic signal amplitude to normalize the total horizontal derivative. Cooper and Cowan (2006) used horizontal tilt angle that normalizes the horizontal gradient amplitude by the vertical derivative. Ferreira et al. (2013) proposed using tilt angle of the horizontal gradient amplitude. Zhang et al. (2014) used the tilt angle of the first order vertical derivative of the total horizontal gradient. Yao et al. (2015) suggested using the normalized enhanced analytic signal. Chen et al. (2017) used modified theta map filters. However, all methods require a reduction to the pole transformation (Li and Pilkington, 2016; Pilkington and Tschirhart, 2017). On the other hand, Cooper (2014) suggested the use of modified analytic signal amplitude that based on tilt angle method as a balanced edge detection filter. Although the method reduces the dependence of the analytic signal amplitude on the magnetization direction, the edges identified for deep sources are generally diffused.

In this paper, we introduce a new edge detection filter based on the derivatives of the analytic signal amplitude and the hyperbolic tangent function to improve the resolution of the edges. The suggested filter is improved also by introducing a modification that results as an enhancement in delineating the edges of the causative sources.

2. Method

The analytic signal (AS) is defined as the square root of the sum of the squares of the vertical and the two horizontal derivatives of the magnetic intensity anomaly M as (Roest et al., 1992);

$$AS(x,y) = \frac{\partial M}{\partial x}\hat{x} + \frac{\partial M}{\partial y}\hat{y} + i\frac{\partial M}{\partial z}\hat{z} \quad (1)$$

where $i=\sqrt{-1}$ and $\hat{x}$, $\hat{y}$ and $\hat{z}$ are unit vectors in x, y and z directions, respectively.

From Eq. 1 it follows that the amplitude function is given by:

$$|AS(x,y)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \quad (2)$$

Li (2006) showed that the AS is not independent of the magnetization direction for the general 3D case. In terms of centering the magnetic anomaly over its causative source, however, the AS can be advantageous over the anomaly itself. To reduce the dependence of the analytic signal amplitude on the source vector direction, Cooper (2014) proposed using tilt angle of the analytic signal amplitude (TA) that based on the ratio of the first vertical derivative and total horizontal derivatives of the analytic signal amplitude.

$$TA = a\tan\left(R\right) \quad (3)$$

where

$$R = \frac{\dfrac{\partial AS}{\partial z}}{\sqrt{\left(\dfrac{\partial AS}{\partial x}\right)^2 + \left(\dfrac{\partial AS}{\partial y}\right)^2}}$$

Although the method can balance the amplitude of edges of different amplitude anomalies, the identified edges of deep geological sources are divergence.

Here, we introduce a new edge detection filter that used the hyperbolic tangent function of the ratio R, which is defined as:

$$HT = \tanh\left(R\right) = \frac{e^R - e^{-R}}{e^R + e^{-R}} \quad (4)$$

The main attributes of this filter are to provide maximal amplitudes on the edges of source body and equalize signals from shallow and deep geological bodies.

It was found that use of a modified hyperbolic tangent function achieved better delineation of the edges of the body than the AS, TA and HT when apply directly to the magnetic data (Fig. 1), i.e.

$$HT_p = \frac{e^R - e^{-R}}{p \times e^R + e^{-R}} \quad (5)$$

where p is a positive constant decided by the interpreter. In general, the value of p is between 0 and 0.1. The introduction of p is to increase resolution of edge detection results. Because the filter is based on a ratio of derivatives, it also enhances large and small amplitude anomalies well.

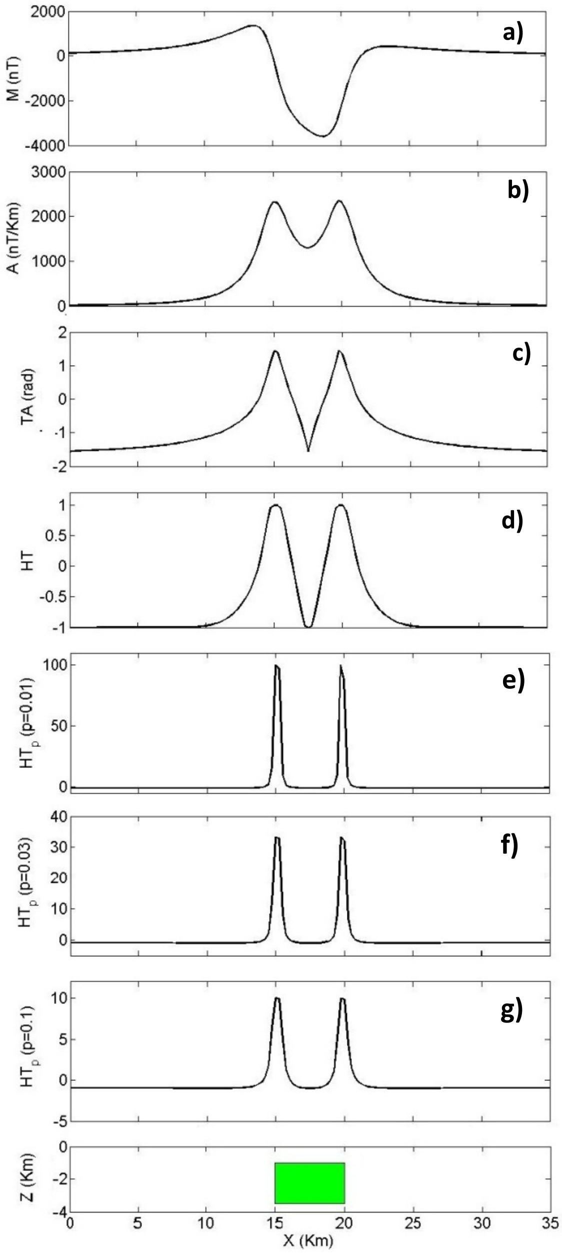

Figure 1. (a) Total magnetic intensity M across a 2D block (green shading) with inclination I=10°. (b) The analytic signal amplitude AS. (c). The tilt angle of the analytic signal amplitude TA. (d) The hyperbolic tangent function HT. (e) The modified hyperbolic tangent function HT_p with p=0.01. (f) The modified hyperbolic tangent function HT_p with p=0.03. (g) The modified hyperbolic tangent function HT_p with p=0.1. The modified hyperbolic tangent function HT_p showing two maxima over the edges of the block

3. Synthetic examples

In order to demonstrate the feasibility of the proposed filter discussed in the previous section, we applied it to three synthetic examples. We also choose two other frequently used well-known filters to compare the boundary detection results. They are the analytic signal amplitude and the tilt angle of the analytic signal amplitude.

Table 1. Parameters of the single prism model

Center coordinates (km)	30, 30	**Length × Width (km)**	20×15
Inclination I (°)	30	**Depth of top (km)**	1
Declination D (°)	0	**Depth of bottom (km)**	2
Magnetization (A/m)	5	**Rotation angle (°)**	60

The first example involves an edge detection from a magnetic anomaly over a single prism model with the geometrical parameters and physical properties listed in Table 1. The magnetic response of the prism was generated using Rao and Babu (1991) algorithm (Fig. 2a). Black lines in this figure also display the outline in plain view of the prismatic source. Fig. 2b, c, and d show the results of the AS, TA, and HT_p, respectively. It can be observed from these figures that the AS is only effective in enhancing two of the four edges of the causative body. The TA is more effective than the AS in enhancing all the edges of the source body, however the obtained result from this filter is diffused to some extent. It is observable here that the HT_p filter produced better resolution at the edges than the other filters. The result is in good agreement with the real edges of the causative body, although there is a small amount of distortion at the corners of the causative body which breaks down at these parts.

The second example involves three prisms models with the same dimensions in size but in increasing depths at different horizontal positions. Prism P1 is the shallowest, whereas P2 is intermediate and P3 is the deepest. Their parameters are shown in Table 2. Fig. 3 shows the synthetic magnetic anomaly map due to these prisms models. All prisms are defined with a magnetization of 5 A/m. The theoretical magnetic anomalies are calculated using the formula given by Rao and Babu (1991) on a regular grid with a spacing of 0.5 km. The outlines of the sources are shown by the black lines in planar view. Fig. 4a displays the result of the AS. Because the AS is dependent on the

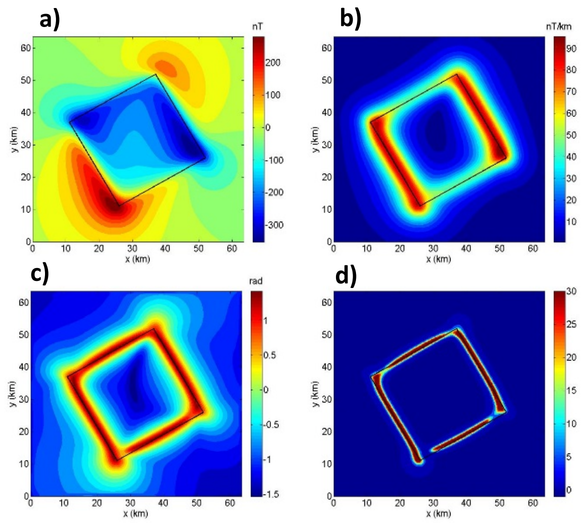

Figure 2. Test results of the single prism model (a) Synthetic magnetic anomaly of the single prism model, (b) AS (c) TA, (d) HT_p, with p = 0.03

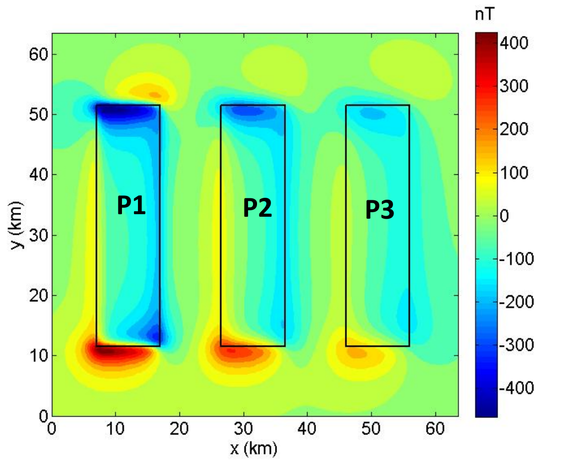

Figure 3. Synthetic magnetic anomaly of the three prisms

inclination of the magnetic field, it can be seen that the AS delineates only two of the four edges of each causative body. The AS also cannot balance anomalies from shallow and deep sources. Fig. 4b shows the TA of the magnetic data. Clearly, the TA is less dependent on the direction of the source magnetization and its maximum values are in position close to the edges, even for deeper sources. Fig. 4c displays the edges detected by the HT_p filter. It can be clearly observed that the amplitude of the response from the varying depth bodies is similar, although the response from the deeper body is rather diffuse. The results show that the HT_p results in a higher resolution and enhances the edges to be more visible and sharp, compared to the AS and TA filters. Clearly, the HT_p filter is also slightly dependence on the direction of magnetization.

Table 2. Parameters of the three prisms model

Prism ID	P1	P2	P3
Center coordinates (km)	12; 31.5	31.5; 31.5	51; 31.5
Inclination I (°)	12	20	18
Declination D (°)	25	26	27
Magnetization (A/m)	5	5	5
Length × Width (km)	40×10	40×10	40×10
Depth of top (km)	1	2	3
Depth of bottom (km)	2	3	4
Rotation angle (°)	0	0	0

The sensitivity of the method to random noise is studied by adding random noise with amplitude equal to 0.01% of the original data. To reduce the noise effect, upward continuation of 0.1 km is applied to the derivatives of the analytic signal prior to calculations of HT_p. Fig. 4d shows the edge detection result using the HT_p filter after upward continuation of 0.1 km. In this case, the obtained result also compares favourably with the theoretical model.

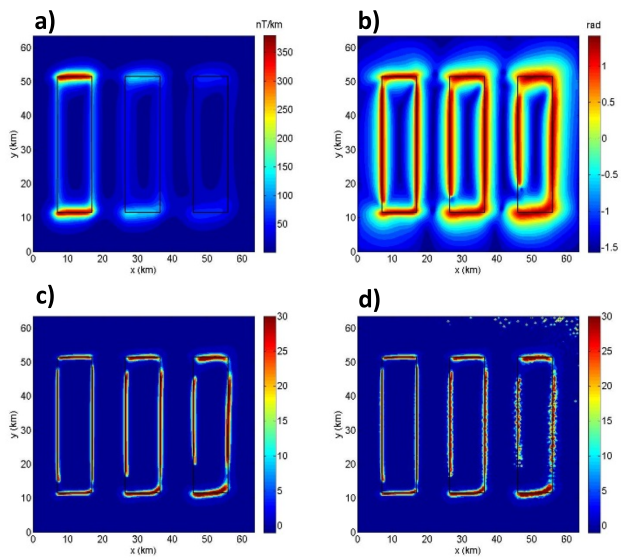

Figure 4. Test results of the three prisms model. (a) AS (b) TA, (c) TH_p, (d) TH_p with the random noise and p = 0.03

The third and last example involves edge detection from a magnetic anomaly over two prisms models both with low magnetic inclinations and are in superposition of their locations. One is smaller and closer to the surface (PrismA), and the other is located beneath the first and is partially hidden (PrismB). Parameters of the two sources are given in Table 3.

Table 3. Parameters of the superposition two prisms models

Prism ID	A	B
Center coordinates (km)	42; 30	28; 31
Inclination I (°)	10	5
Declination D (°)	0	0
Magnetization (A/m)	4	5
Length × Width (km)	15x15	20x25
Depth of top (km)	1	2
Depth of bottom (km)	2	4
Rotation angle (°)	45	45

Fig. 5a shows magnetic anomaly due to these prisms. Black lines in this figure also display the outline in plain view of the prismatic sources. Using this field, Fig. 5b, c, and d show the results of the AS, TA, and HT_p, respectively. In this case, as expected from the previous example, the AS represents a poor view of the edges for the deeper PrismB because of its disadvantage in balancing anomalies from shallow and deep sources. On the other hand, the amplitudes obtained for PrismA in AS also are not steady along the borders of the prism. However, in spite of the interference effects from neighbouring source, it is observable that both the responses of TA and HT_p can balance the amplitudes of deep and shallow (Fig. 6) and satisfies good correlation with the true edges of both prisms, even the one is deeper and the prisms are in superposition. Hence, by comparing TA and HT_p, we can conclude that the proposed filter HT_p results in a higher resolution to bring out the edges of the causative sources while the change of the response close to the borders of the bodies are much sharper than the TA (Fig. 6).

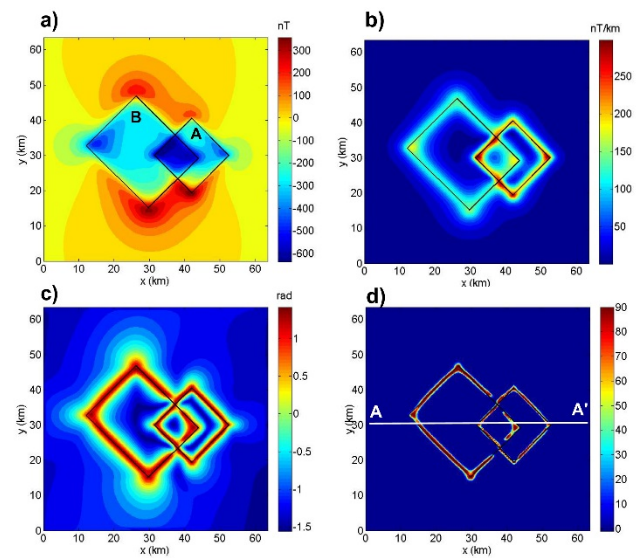

Figure 5. Test results of the super positioned two prism models. (a) Synthetic magnetic anomaly, (b) AS (c) TA, (d) HTp, with p = 0.03

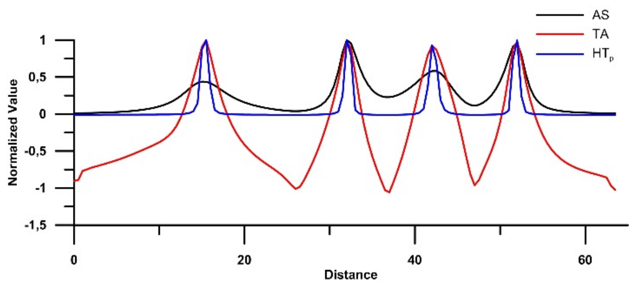

Figure 6. Data of AS, TA, HT_p along profile AA' shown in Fig. 5

4. Conclusions

We have presented a new edge detection filter that based on the hyperbolic tangent function and the ratio of the first vertical derivative and total horizontal derivatives of the analytic signal amplitude. Unlike almost other edge detection methods that require a reduction to the pole or pseudo-gravity transformation prior to application, the TH_p filter can be applied to the magnetic dataset directly. Test results on synthetic data cases show that the TH_p filter give a higher resolution, compared with other edge detection filters such as the AS or TA. This filter therefore allows us to better detect geologic boundaries of causative sources, making an improved geological interpretation possible.

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Conflict of Interest

No conflict of interest was declared by the authors.

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