NEAR SURFACE GEOPHYSICAL ANOMALY MODELING AND DETECTION IN MATLAB

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Abstract

The near surface geophysical survey is often focused to detect and classify an anomaly located near to the Earth surface. The anomaly detection can be applied in the archaeological survey, in the stability of soil classification during the pre-construction survey or for example to detect cavities in dams after a disaster. Our current work was inspired by an idea to use the geophysical methods in the rescue operation directly after a disease. Such application has several typical constrains resulting in the fact that we have to semi-automate the recognition process. We have decided to focus to the potential fields based methods such as gravimetry or polarization methods.

The anomaly recognition process is based on pattern detection in the acquired data. Body by body, method by method, we have described typical pattern of the anomaly in the acquired data. Based on the corresponding physical model we are looking for a relationship between the pattern characteristics and physical body parameters. For example, with measuring of the gravity field we can detect a body with different mass (a cavity in dam for example). The spherical body corresponds with typical circular shape with central maximum value. The distance between the center of the anomaly and circle with absolute value equal to half of the maximum is a linear function of the real body depth and mass.

1 The Anomaly

A general function presenting a symmetric potential field anomaly can be expressed by simple equation (Salem, 2011):

$$f(r) = F * (r^2 + x^2)^{-q} \qquad (1)$$

The F is an amplitude factor, q is a shape factor characterizing the shape of the anomaly. The r and x are coordinates related to anomaly location: r is the distance from the middle point of the anomaly to the observation point on the surface, z is the depth. Detailed summary of q and F values for different simple geometrical bodies both for gravity and magnetic sources is given in Table 1 (referenced form Salem, 2011). More complex anomaly geometry can be derived from theory presented in the Blakely (pages 192-213).

Table 1: THE F AND Q FACTOR FOR SIMPLE GEOMETRICAL BODIES, GRAVITY FIELD (Γ IS GRAVITATIONAL CONSTANT, M IS MASS FOR THE SPHERE AND DENSITY CONTRAST TIMES CROSS-SECTIONAL AREA FOR THE CYLINDER).

Anomaly type	F	Q
Sphere	γMz	3/2
Horizontal cylinder	2γMz	1
Vertical cylinder	γM	0.5

Considering simple anomaly bodies, the f function is a smooth function; maximum value is located above the anomaly center. If the anomaly field is presented as 2D image, it gives spherical contours for sphere and vertical cylinder, for horizontal cylinder we obtain linear contours.

For all three bodies a linear dependency between the depth of anomaly center (z) and the surface location of the half-maximum value:

$$z = k * x_{0.5} \quad (2)$$

The k value differs with anomaly type and its value can be extracted directly from the equation (1) (Mares 1990, pages 55-57). The z value can be later used to estimate the density (or mass) of the anomaly directly from the equation (1).

Table 2: THE VALUE OF THE K PARAMETER FOR DIFFERENT ANOMALY TYPES.

Anomaly type	**K**
Sphere	1.305
Horizontal cylinder	1
Vertical cylinder	√3/3

2 The Detection Process

The detection process itself contains following steps (all the steps are described deeply later in the text):

1. The noise level enhancement based on histogram analysis (optional, not covered in this paper).
2. Smoothing, if noise is detected (optional, not covered in this paper).
3. The detection of areas with value close to maximum and half maximum.
4. Conversion of the maximum and half maximum matrices into black and white pictures.
5. Line detection in maximum matrix – a line significant for horizontal cylinder. The detection of sphere and vertical cylinder is started otherwise.
6. Shape detection in half maximum matrix to measure the appropriate $x_{0.5}$ value using the maximum and half maximum matrix.
7. The parameters estimation and calculation of estimated anomaly field. If no lines detected in the image, both spherical and cylindrical fields are calculated and compared with original image – the closest shape is selected.

3 Shape Detection

As the first step the maximum and half maximum matrix is created: All the values higher than 98 % of the maximum are colored in white, other left black in the maximum matrix (MM). All the values higher than 50 % of the maximum are white in the half maximum matrix (HM).

Line detection process is now necessary to distinguish the horizontal cylinder and other anomalies – it is necessary to set up the thresholds of following erosion process. We use the Hough transform implementation from Matlab.

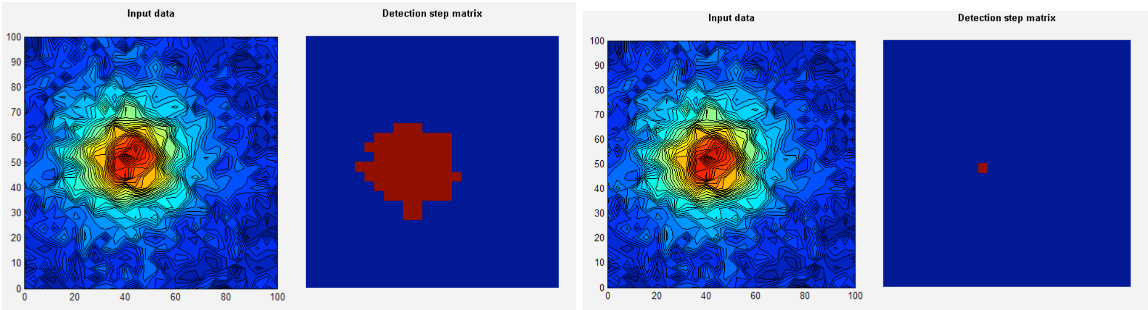

Figure 1: The spherical anomaly with noise (left picture, noise level is from 0 to 0.2 of the maximum value) and corresponding HM and MM matrixes.

Next step is the erosion of the MM matrix, as the erosion pattern is used the Golay alphabet, the L element (Golay 1969). The aim of the erosion is thin the white areas (for a pixel or a single line). This way we get the location of the middle of the anomaly.

Now the HM matrix is taken into the account. If lines were detected, we run the line detection again, to get the border of the half value area (half middle line). The distance between the middle line and half middle line is calculated using standard algebra algorithms for the line distance measurements.

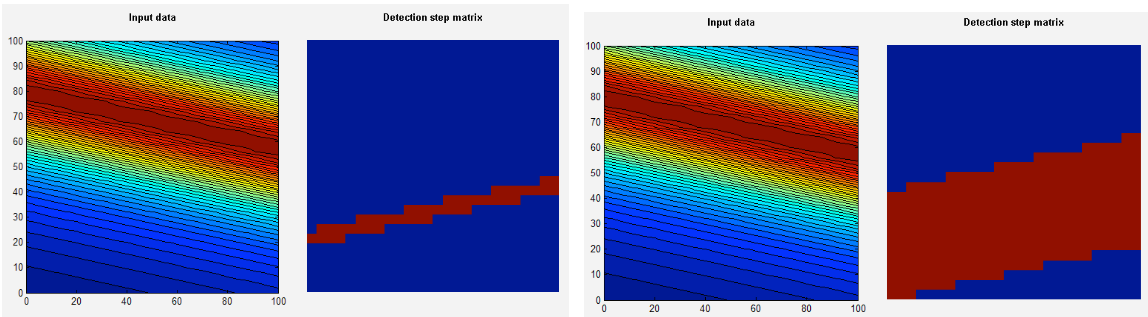

Figure 2: The horizontal cylinder without noise and corresponding MM and HM matrixes after erosion

If no line is detected, we estimate the width and height of the white area in HM matrix. If the shape is not close to the circle, the process ends with result “no desired anomaly is detected”. Otherwise, the distance from the middle point to the border of the half maximum circle is measured.

Measured distance is in the next step used to estimate the density or mass of the anomaly.

The estimated parameters are used with equation (1) to calculate the estimated anomaly field. If the horizontal cylinder was already detected in the data (the initial line detection was successful), the process ends.

If no lines were detected, it is necessary to distinguish the sphere and vertical cylinder. The eucleidian distance between the input (f_i) estimated (f_e) field is measured point by point for both estimated anomaly fields and input data.

The result is the distance matrix. The mean value of this matrix is taken as the error number *ErrNum*, the description of the similarity of input and estimated field. The less is the *ErrNum*, the closest are values in the input and estimated field. The estimated shape of the anomaly is selected as the shape of the estimated data with lower *ErrNum*.

3 Conclusions

The presented shape detection algorithm detects the analytical anomaly body in both noise-free and noise data. If low level noise is presented in the data, the algorithm works well without smoothing the data; higher level of noise in the data requires the smoothing.

The spherical anomaly detection with high level of added noise is presented in Figure 6, horizontal cylinder with the same level of noise in Figure 7, vertical cylinder is presented in Figure 8. In all figures, the data area is 100x100 m with 4 m step.

In general, the estimation error differs from 80 % to 99 % in the depth and location estimation. The geometry is detected correctly in 80 %. The most of the failures is obtained with high noise and horizontal cylinder. For the future we plan to enhance the shape detection of HM matrix to obtain the more precise detection and to improve the comparison of the similarity of the estimated and input data.

The real application of presented algorithm requires to define the desired anomaly body and to modify the proper way the shape detection steps.

If no desired anomaly is presented in data, we can see it in histogram and also during the shape detection process (the HM matrix has different than excepted characteristics).

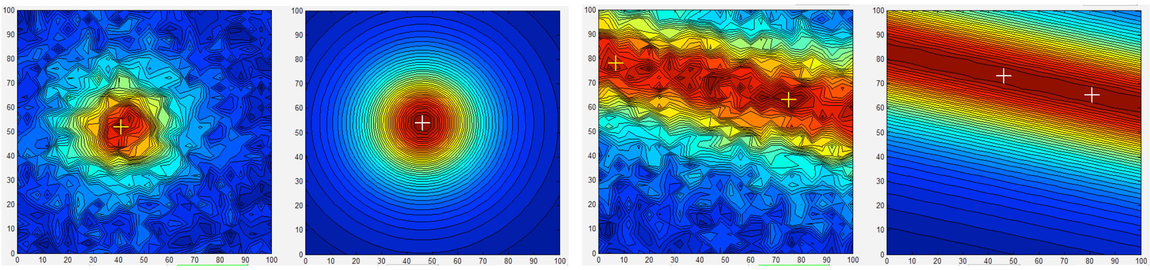

Figure 5: A spherical anomaly combined with noise (top left picture, noise level is from 0 to 0.2 of the maximum value) and estimated value. Original depth is 23 m, estimated is 25 m. The right picture presents a horizontal cylinder with noise (left picture, noise level is from 0 to 0.2 of the maximum value) and estimated value. Original depth is 22 m, estimated is 23 m.

References

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