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Body edge delineation in 2D DC resistivity imaging using differential method

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Abstract. DC resistivity is widely used to identify the kind of rock and the lithology contact. However, the image resulting from resistivity processing is shown in a contour image. There is be a problem to interpret where the edge of body location is. This study uses differential method to delineate the edge of body in DC resistivity contour. This method was applied to the boundary between gravel and underlying clay layer. The first and the second order differential method is applied to the delineation of lithology contact. The profiling curve has to be sliced and extracted from the resistivity contour before the differential method can be used. The spectral analysis shows the frequency and wavenumber of the profiling curve used to make gridding. The slicing process was conducted horizontally and vertically in order to get the mesh size which will be used in the differential method. The second order differential, the Laplace operator, is able to show the edge of body more clearly than the first order differential and shows the contact between gravel and clay.

1. Introduction

The geo-electrical 2D resistivity technique is widely used to investigate natural resources, archeology, geo-technique [1], hydrogeology and several environment problem [2,3]. The result of geo-electrical 2D resistivity imaging is usually shown as a contour map. It contains not only the information of lithology interpreted from resistivity value but also the information of the shape of the resistive body interpreted from shape of contour. Ambiguity often occurs when the contact of body lithology is to be determined. It is due to the degradation of color or limitations of contour interval on cross-section of 2D geo-electric. Therefore, the interval of contour should be set in order to reduce noise. Furthermore, we are able to focus on the investigated object. Many techniques have been developed to reduce the noise and to erase the outlier on the resistivity data [4,5]. Solving the ambiguity problem by numeric and simulation processing is very important and helpful to determine a resistivity model for the electrical imaging survey of the subsurface [6].

2. Method

The second order differential method or the Laplace operator method was used to analyze the contact of the body resistive on the result of 2D geo-electric imaging. This method uses a simple calculation to detect the body edge and is widely used in image processing for the edge detection technique. As we know, the data of 2D DC resistivity measurements has weakness in interpretation of the body edge. Figure 1 shows DC resistivity contour image in gravel-clay layering [4,7].

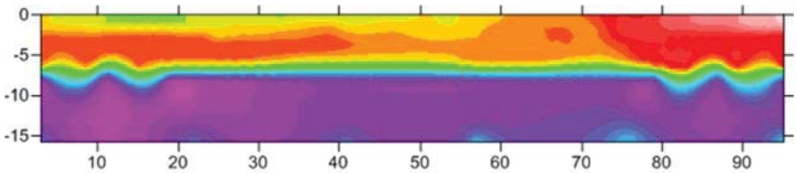

Figure 1. Resistivity contour from Gravel and underlying clay layer [8]

This technique combines differential method and the spectral analysis. The differential method was used to detect edge of body resistive while the spectral analysis was used to optimize computation process. Variable of Δx and Δy are used on Laplace operation to calculate the crossing zero, then the spectral analysis is able to give the optimal value based on the resistivity profile which is made to extract the wave number using Fourier transform and to calculate the mesh sizes Δx and Δy.

2.1 Spectral analysis
The calculation of spatial mesh is begun by slicing the contour lines of 2D DC resistivity data with x and y direction, where the profile attribute on vertical axis is resistivity (Ωm) and on horizontal axis is length or depth (m). The resistivity profile in spatial domain is processed by using Fast Fourier Transform (FFT) to separate the high and low frequency. The profile of high frequency requires a small grid size of Δx or Δy and the computational process will be costly while the profile of very low frequency creates large grid size and the resolution process become coarse. The cut off frequency is calculated to find the optimal point between high and low frequency, it is written as:

$$\rho'(f) = \int_{-\infty}^{\infty} \rho(x) e^{-j2\pi f x} dx \tag{1}$$

where $\rho'(f)$is the resistivity frequency profile, $\rho(x)$ is the resistivity profile, f is frequency, x is the length or depth. In this way, the resistivity profile has to be made perpendicular to contour line. It will show slope on graphic and have multiple frequency on it. Zero frequency is caused by homogenous resistivity. The cut off frequency was extracted from resistivity frequency profile using FFT. The technique is the same as residual-regional separation on gravity method.

2.2 Differential Method
Pierre de Fermat has developed a differential algorithm to define the maximum, minimum and slope value of a special function. He used the first order differential as a technique to calculate the gradient of a curve. Figure 2 presents the gradient of a curve as the result of the first order differential. The direction of gradient line is written in the gradient value. In the process of the edge detection, the maximum and minimum values of the original function are not as important as the slope which presents the gradation contour that has the edge information. The first order differential generates the maximum and minimum values at the slope, then it results various values if the slope has multi-gradient so that it can cause confusing interpretation. The second order differential or the Laplace operator could be used to resolve that problem.

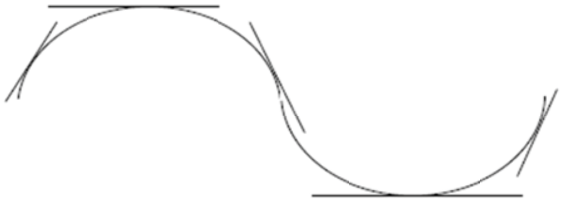

Figure 2. Gradient on the curve as the first order differential process

The result of Laplace operation is better than the gradient operation. The zero crossing that is produced by Laplace operation correspond to the slope in original curve or maximum value in gradient operation. It can be used to get the position of the edge accurately. The Laplace operation is written in equation (2) and the numerical solution is written in equations (3) and (4). Figure 3 shows the logical process on the application of differential method.

$$\nabla^2\rho = \frac{\partial^2\rho}{\partial x^2} + \frac{\partial^2\rho}{\partial y^2} \tag{2}$$

$$\frac{\partial^2\rho}{\partial^2 x} = \frac{\rho(x_{i+1}, y_j) - 2\rho(x_i, y_j) + \rho(x_{i-1}, y_j)}{(\Delta x)^2} \tag{3}$$

$$\frac{\partial^2\rho}{\partial^2 y} = \frac{\rho(x_i, y_{j+1}) - 2\rho(x_i, y_j) + \rho(x_{i-1}, y_{j-1})}{(\Delta y)^2} \tag{4}$$

In this case, x and y are position data, i and j are the index of grid, Δx and Δy are the mesh site. Δx and Δy are extracted from the spectral analysis with FFT.

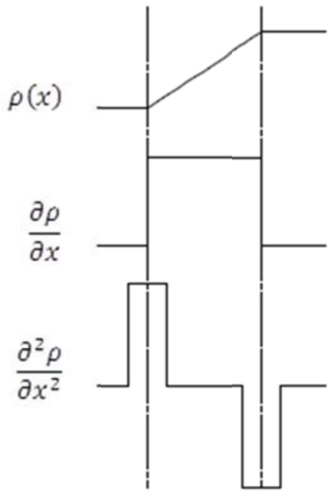

Figure 3. The illustration of Laplace operation that define the edge on 1D slope curve

3 Results and Discussion

This developed technique has been tested by experimental data that has been known and interpreted as a model. The surveyed field contains gravel, clay and sand layer [8]. It has been confirmed by seismic refraction data. The challenge is how to determine where the contacts of gravel, clay and sand are. Spectral analysis and Laplace operator has been done to find the edge of the resistive body.

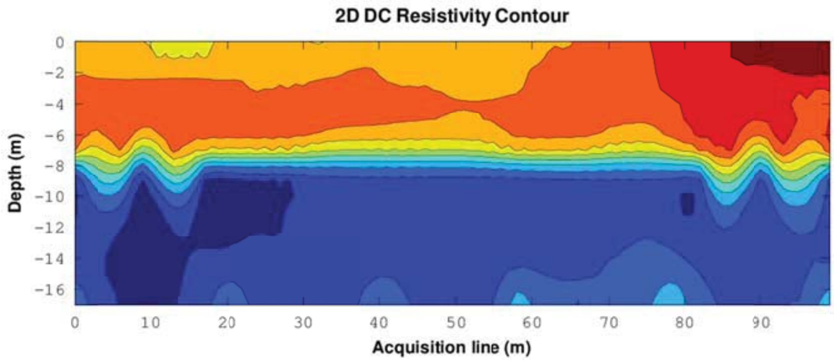

Figure 4. Resistivity contour image from Clifton survey that has gravel, clay and sand layer as a model

Figure 4 shows resistivity contours image that have high resolution grid. The grid was built by meshes of 0.2 meter. Total acquisition length is 100 m end depth is 18 m. The distance between electrodes is 2 meter. The contour appears to have two layers that show a high and low resistivity, respectively. In fact, there are three layers vertical respectively. Robust inversion method has been used to find the layers [9]. Here, the data is used to examine our technique.

The first step on the edge detection using Laplace operation and spectral analysis is to slice the contour data and get the resistivity profile. Slicing data can be digitized randomly, but fine digitization is better than coarse one. After that, the resistivity data is calculated by spectral analysis to get wave number and find the interval gridding optimum ΔxandΔy. Figure 5 shows the spectral analysis process. High wave number is interpreted as noisy signal response and it will make the Laplace operation very costly because gridding interval becomes very small. Low wave number will make the Laplace operation is very coarse and low resolution so the edge cannot be determined exactly, but numerical process is conducted faster than high wave number value. The optimum value is determined as the intersection of the linear trends at low wave number and high wave number. It is similar to the cut off frequency in filter processing [10].

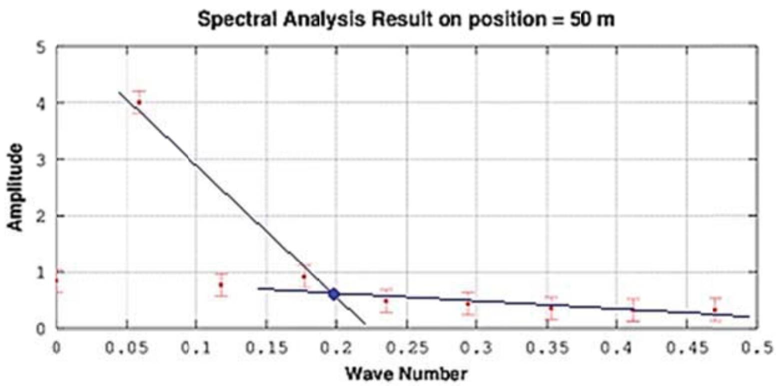

Figure 5. Result of spectral analysis to find wave number and calculate optimum spatial gridding

After the spectral analysis process, the next step is Laplace operation process. Numerical solution is very helpful in this process. The second order differential can be solved by forward and backward difference. Laplace operation process is conducted to resistivity data contour that has been gridded by new spatial gridding. It should have less data than the original one, but it does not lose the contact body information. The result of this process is the map of the new contour line that has zero value. The map shows the zero crossing made by Laplace operation and the position of the edge of the resistive body. Figure 6 shows zero value map as a position of body contact.

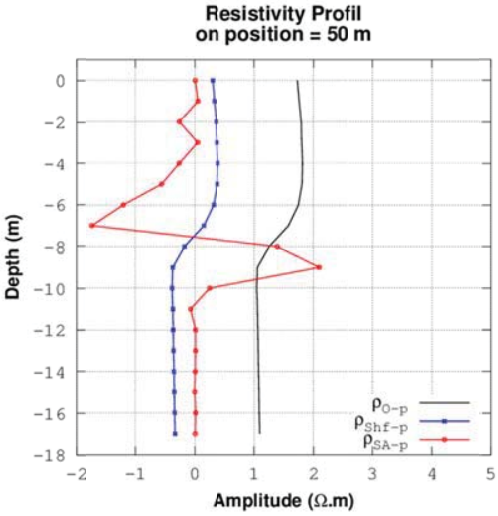

Figure 6. Resistivity profile extracted from contour on acquisition position of 50 m. The black line is original data before shifting. The blue line is data shifted across the $\rho = 0$. The red line is the result of Laplace operation.

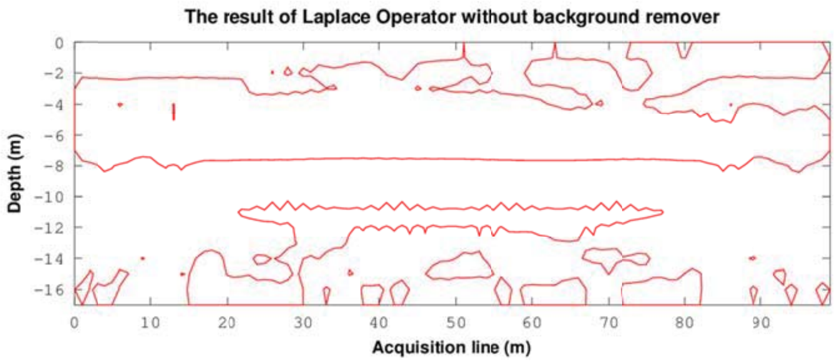

Figure 7. Zero crossing map that resulted by Laplace operation on resistivity contour to determine the edge of body contact.

In Figure 7, we can see various zero contour lines. At this paper, we don't use removal background technique to remove zero value that caused by Laplace operation in homogeneous resistive body. A homogenous resistive body can appear as noise in Laplace operation because a flat line that has no slope could lead to zero value when Laplace operation was conducted. To resolve this problem, background removal is important, but it will be discussed on another paper.

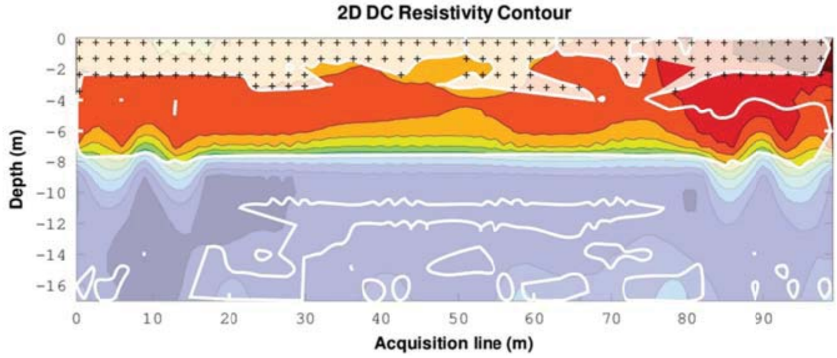

Figure 8. The result of gravel-clay-sand boundaries model overlay without background removal

Figure 8 shows model boundaries as a result of the edge detection technique on gravel-clay-sand layers. We can see the boundaries clearly, so the delineation process was successful on this model. As a note, the process has been done without background removal for noise clearance. The method can be developed to calculate the prospective natural resources exactly. Boundary detection can used to calculate the volume of prospect, so the saving of resources can be predicted accurately [11].

4 Conclusions

The combination of the spectral analysis and the Laplace operation give the boundary of resistive bodies clearly at depth 8 meter from the surface. It is demonstrated by Clifton survey data that has three layers, gravel underlying clay and sand layer. This model has been accepted as a subsurface interpretation.. Besides, the computational process to calculate the edge of body is faster because it is processed by optimal value of mesh size. In future work, this method can be used to calculate the body prospect in subsurface mapping based on 2D resistivity imaging.

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