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Identification of Buried Archaeological Objects with Radial Derivative of Micro Gravity Data

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ABSTRACT

The development of recent gravimetric technology allows us to measure gravity anomalies with accuracy of micro Gal. Micro gravity is able to detect very small gravity anomalies such as anomaly due to buried archaeological objects below the earth surface in certain depth. Radial Derivative of gravity data is used to sharpen anomaly due to lateral changes of density contrast. Horizontal derivative carried out by previous researchers have some weaknesses, i.e. the loss of derivative values in certain directions and inconsistence values at the source boundary of the same anomaly edge. To solve the horizontal derivative problem, a Radial Derivative is made. Radial Derivative is derivative of gravity anomaly over horizontal distance in the radial direction from a certain point which is considered as the center of anomaly. There are two kind of Radial Derivative i.e. First Radial Derivative (FRD) and Second Radial Derivative (SRD). Blade Pattern is another way to enrich the ability of SRD to detect boundary of anomaly source. Synthetic gravity data of buried archaeological object was made by counting the response of forward modeling. All of programs and calculation of the models in this research is performed based on Matlab® program. The results of the tests on the synthetic data of the model show that the Radial Derivative is able to detect the boundaries in buried temples due to density contrast. The advantage of Radial Derivative which is a horizontal derivative in the direction of radial compared to ordinary horizontal derivative is the ability to detect vertical boundaries of various anomaly due to horizontal layers and capable of showing density contrast in almost all directions

Introduction

The development of recent gravimetric technology allows us to measure gravity anomalies with accuracy of micro Gal. Micro gravity is able to detect very small gravity anomalies such as anomaly due to buried archaeological objects below the earth surface. This measurement also requires high accuracy of positions and elevation measurement up to centimeter. Micro gravity is able to detect very small gravity anomaly due to small objects. One of the capabilities of micro gravity is to identify buried archaeological objects.

Radial Derivative of gravity data is able to sharpen anomaly due to changes in lateral contrast. Horizontal derivative carried out by previous researchers have some weaknesses, i.e. the loss of derivative values in a particular direction and the emergence of inconsistence values at the boundaries. To solve the problem of the horizontal derivative weakness which is usually merely on the x or y direction, in this study a different derivative is used, namely Radial Derivative.

Horizontal derivative and gradient of gravity data has been used in some research to detect boundary of anomaly source. The first horizontal derivative of a gravity anomaly can sharpen anomalous irregularities, as well as the second derivative [1]. Second derivative method is able to interpret gravity anomalies in the anticline zone [2]. Analytic derivative also used to detect fault zones. Detection and analysis are performed to obtain depth and amplitude coefficients related to thickness and contrast density [3]. Gravity gradient data is able to detects boundaries of anomaly source and estimates depth. This method is applied to gravitational anomalies in the Kozakli-Central region, Anatolia, Turkey [4]. Gradient calculations of gravity data in the Tuzgolu basin, Anatolia, Turkey has been tested for interpretation of geological structure boundaries. The results of this study indicate that gradient calculations are capable of detecting both major and minor faults [5]. Multi scale horizontal derivative of vertical derivative (MSHDVD) method was tested in the Foumbon fault zone in Cameroon. The results of field tests show that MSHDVD is able to detect the presence of faults in Foumbon with fault strike direction N 68o E [6]. Vertical derivative analysis has been used to determine the boundaries of vertical lithology to sharpen the analysis of gravitational interpretation in Nigerian Gusau. The results show that the zero vertical second derivative (SVD) is closely related to the lithological boundaries in the area [7]. Slope angle of the normalized total derivative of gravity anomalies has been performed to detect geological structure boundaries. This method has been carried out in the Sea of Oman, southeast of Iran. The results show that this method is better in detecting geological boundaries [8]. Vertical derivative from 3D gravity data has been conducted for interpretation of geological structures. This method has been tested in a very wide area i.e. Central Java to Eastern Java and Madura [9].

Radial Derivative was proposed for the first time to identify boundary of anomaly source[10]. The results showed that this method was able to show vertical boundaries of anomaly source with various advantages compared to ordinary horizontal derivative methods [11]. Radial Derivative are derivative of gravity anomaly over the horizontal distance in the radial direction from a certain point which is considered as the center of the anomaly. Radial direction is chosen to get the maximum derivative value from various anomalies. The advantage of Radial Derivative compared to ordinary horizontal derivative that merely in the one direction (x or y only) is the ability to detect vertical boundaries of various anomalies due to large horizontal layers and the ability to show density contrast in almost all directions.

Theory and Calculation

Gravitational potential at point P (x, y, z) due to continuously distributed mass with the density of ρ *(α, β, γ)* is given by:

$$U(x,y,z) = G \iiint [\Delta\rho\ (\alpha,\beta,\gamma)/\{(x-\alpha)^2 + (y-\beta)^2 + (z-\gamma)^2\}^{1/2}\ ]d\alpha\ d\beta\ d\gamma \qquad (1)$$

The components of vertical and horizontal gravity due to the density distribution are obtained by differentiating equation (1) against x, y, and z, where the results are:

$$\Delta g_z(x,y,z) = -\partial U(x,y,z)/\partial z$$

$$\Delta g_z(x,y,z) = -G \iiint [\Delta\rho\ (\alpha,\beta,\gamma)(z-\gamma)/\{(x-\alpha)^2 + (y-\beta)^2 + (z-\gamma)^2\}^{3/2}\ ]d\alpha\ d\beta\ d\gamma \ (2)$$

Equation 2 shows that the gravitational acceleration g on the earth's surface varies and its value depends on the distribution of mass below the surface which is controlled by geometry (structure) and density. The gravitational field g is also known as gravitational acceleration with units of Gal.

To find out the form of convolution equation in a gravity anomaly, the vertical component of gravity equation 2 is taken:

$$\boldsymbol{\Delta g_z(x,y,z)} = \int_0^\infty \int_{-\infty}^\infty \int_{-\infty}^\infty \boldsymbol{\Delta\rho\ (\alpha,\beta,\gamma).\ R_z(x-\alpha, y-\beta, z-\gamma) d\alpha\ d\beta\ d\gamma}$$

$$= \boldsymbol{\rho\ (\alpha,\beta,\gamma) * R_z(x,y,z)} \qquad (3)$$

where

$$\boldsymbol{R_z(x,y,z) = K.z/(x^2 + y^2 + z^2)^{3/2}}$$

(α,β,γ) is coordinates position of mass element , *G* is gravity constant, *(x,y,z)* is coordinates position of measurement point and *z* is the depth of mass as an anomaly source. Equation (3) shows that the gravity anomaly is convolution between the density distribution *Δρ (α,β,γ)* and the convolution operator *Rz (x, y, z)*. This operator depends on the shape and depth of objects [12]. Synthetic gravity data of buried temple model is calculated by convolution in equation 3. The values of $\boldsymbol{\rho\ (\alpha,\beta,\gamma)}$ are distributed as the form of temple model shown in figure 1. The result of synthetic gravity data as the yields of convolution is shown in Figure 2.

Experimental Method

All of programs and calculation of the models in this research is performed based on Matlab program. The model of the buried object is in the form of a temple. The temple model consists of three components, i.e. the temple fence and gate, the temple altar, and the main temple (center of the temple). The program to make synthetic gravity data allows us to choose the value of the rock density forming the temple and the density of burial material around the temple.

Models are made with model variables based on real values in the field in the form of: density rock forming the temple and density of burying mass. The density of rock forming temple is 4 g/cc which is usually igneous rock. The density of burying mass is 1.5 g/cc so that the density contrast value is 2.5 g/cc. The depth of the buried temple is 6 meters. The shape of the temple model is shown in Figure 1.

The gravity anomaly response of the buried temple model of figure 1 is shown in Figure 2. Maximum gravity anomaly response in the center of the temple is 20 milli Gal. There are some shifting on coordinates of figure 2 due to convolution process. The coordinates of the model and response merely show the scale, rather than position. Radial Derivative of the synthetic gravity anomaly from the forward modeling is then used to identify boundaries of temples part. This Radial Derivative program is based on a numerical approach of derivative value. This program is made with certain grid values with various technical considerations i.e. depth of anomaly source and wavelength of anomaly response.

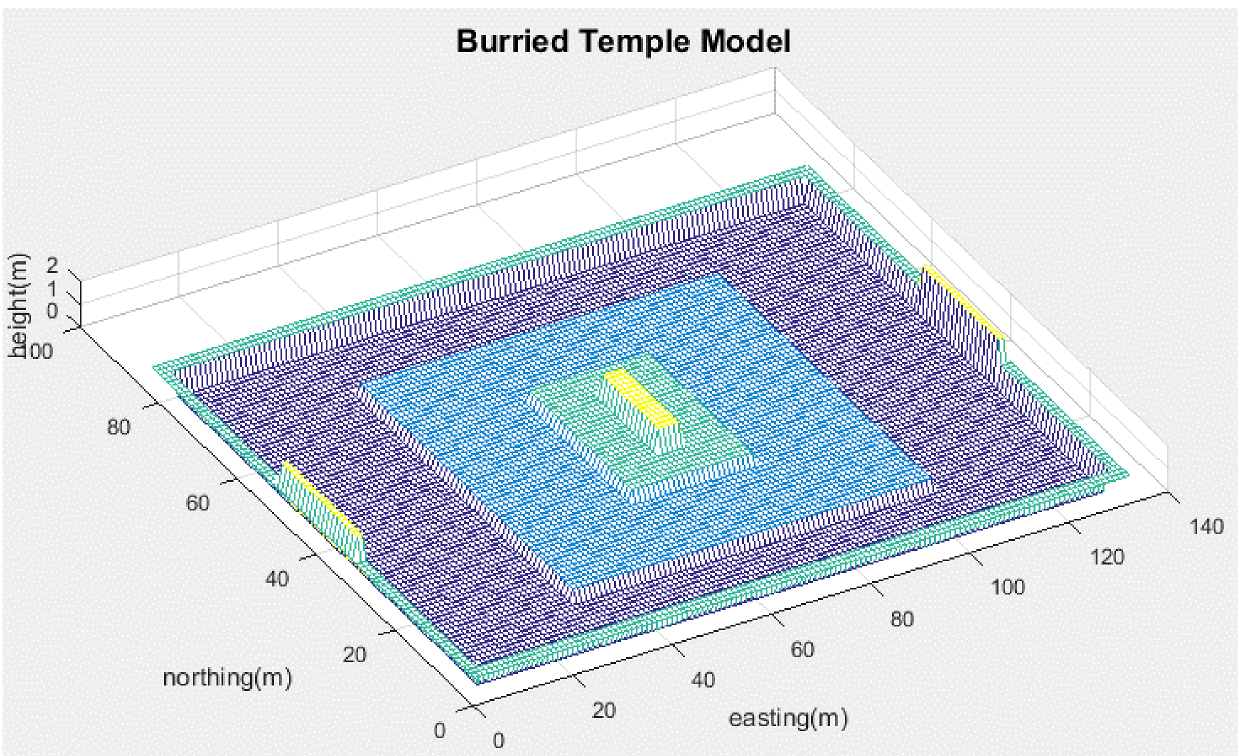

Figure 1. Model of buried object in the form of a temple

Gravitational field is a continuous field which in every space and time always has a certain value. Each position at a certain coordinate has a gravity value due to mass with a certain density. Usually, measurement of gravity using gravimeter is not performed on regular coordinates, but in a random position considering the ease of access to the place. Gravity values with regular coordinates can be performed by gridding.

There are several gridding methods that can be done to get the gravity value on regular coordinates. In this program the triangulation gridding method was chosen because gravity anomaly of the model has a small wave length.

The numerical approach to dg_x values is the difference in the value of g_x on a grid i subtracted by the value of g_x on the previous grid (i-1) on the x axis which can be written as follows:

$$dg_{x(xi+1/2,yi+1/2)} = g_{(xi,yi)} - g_{(xi-1,yi)} \tag{4}$$

in the same way, the value dg is the difference in the value of g on a grid i subtracted by the value of g on the previous grid (i-1) on the y axis which can be written as follows:

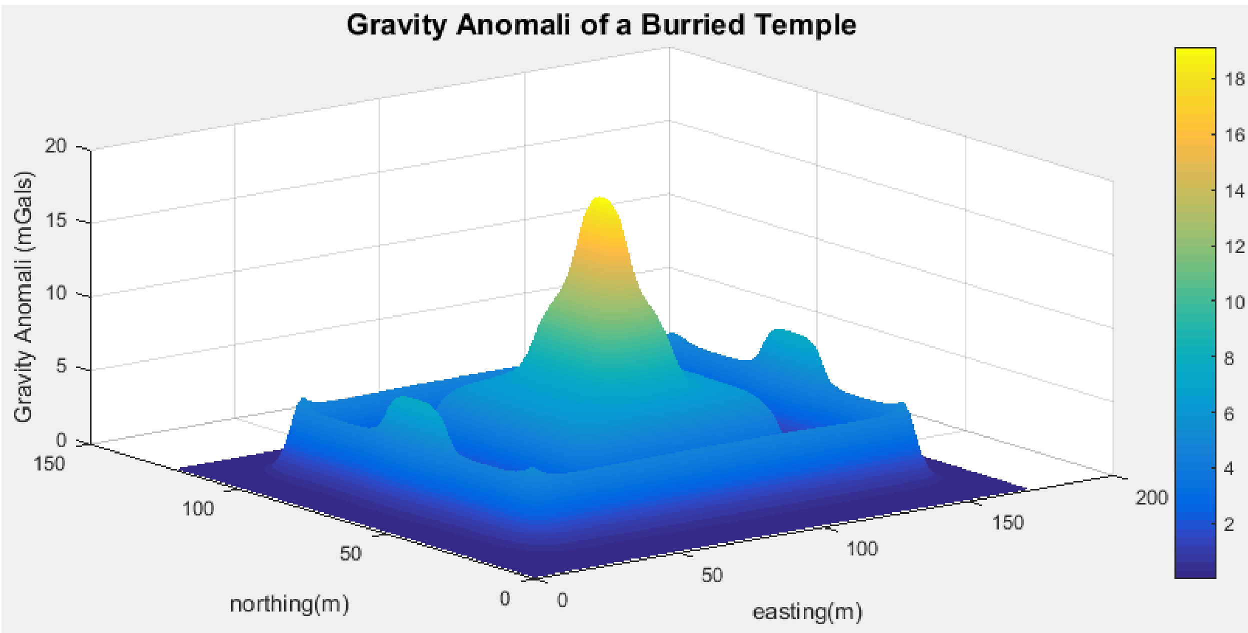

Figure 2. The synthetic gravity anomaly as a response of the buried temple model

$$dg_{x(xi+1/2,yi+1/2)} = g_{(xi,yi)} - g_{(xi,yi-1)} \tag{5}$$

while the derivative value in the radial direction according to equation (5) is:

$$dg_{R(xi+1/2,yi+1/2)} = dg_{x(xi+1/2,yi+1/2)}.\cos\theta + dg_{y(xi+1/2,yi+1/2)}.\sin\theta \tag{6}$$

It should be noted that the grid of Radial Derivative data always shifts by half of the grid space on the anomaly map.

Result and Discussion

The results of the Radial Derivative of synthetic gravity anomaly as a response of temple model is shown in Figure 3. This figure shows the sharpness of the Radial Derivative to identify the boundaries of vertical anomaly of a horizontal layer.

Blade Pattern Program is intended to get a sharp pattern of anomaly map due to vertical density contrast on various sources of anomaly. This program has been tested and applied to the buried temple model. Radial Derivative have been discussed which consist of first Radial Derivative (FRD) and second Radial Derivative (SRD).

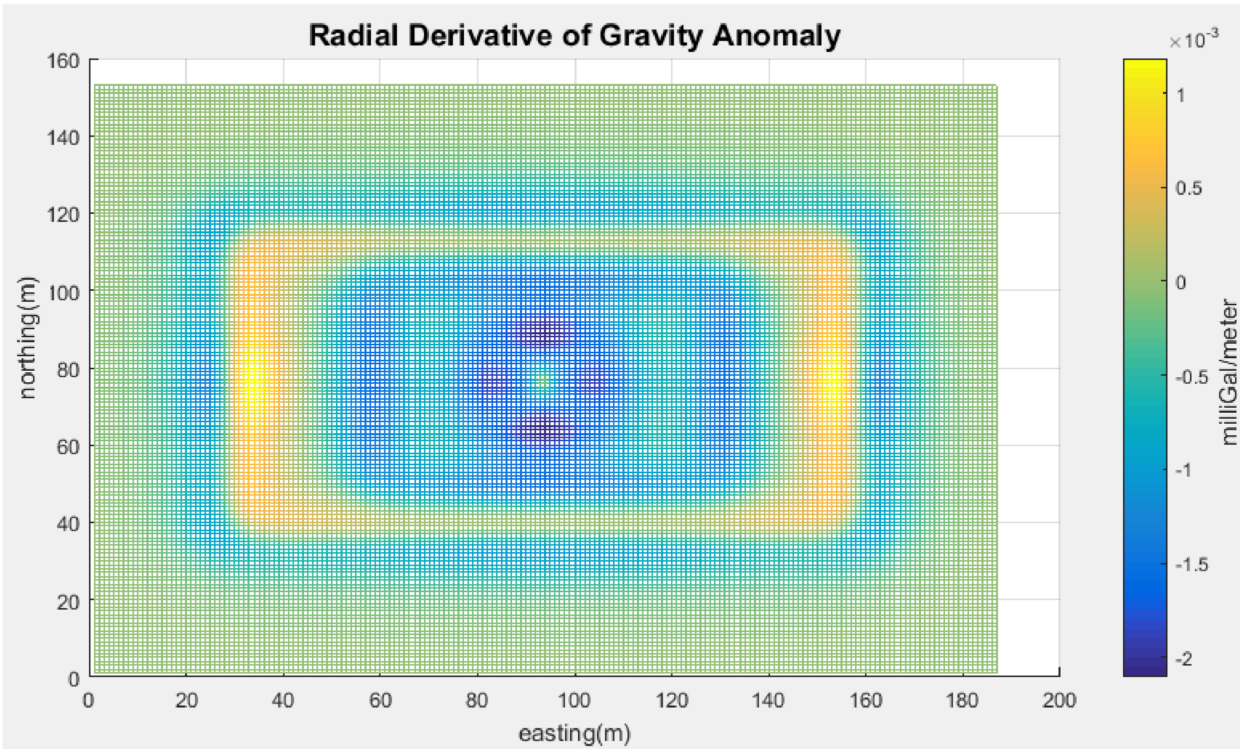

Figure 3. Radial Derivative of 4D gravity anomalies in buried object models

SRD has a small value in the area of density contrast. It means that small value of SRD is actually a boundary of anomaly source. Blade pattern distinguishes SRD of certain small values and cuts other bigger values of anomaly. Figure 4 shows the results of the blade pattern on SRD values from the anomalies of buried temple models. The small value area of SRD is shown in red zones, while the bigger values are indicated by blue zones.

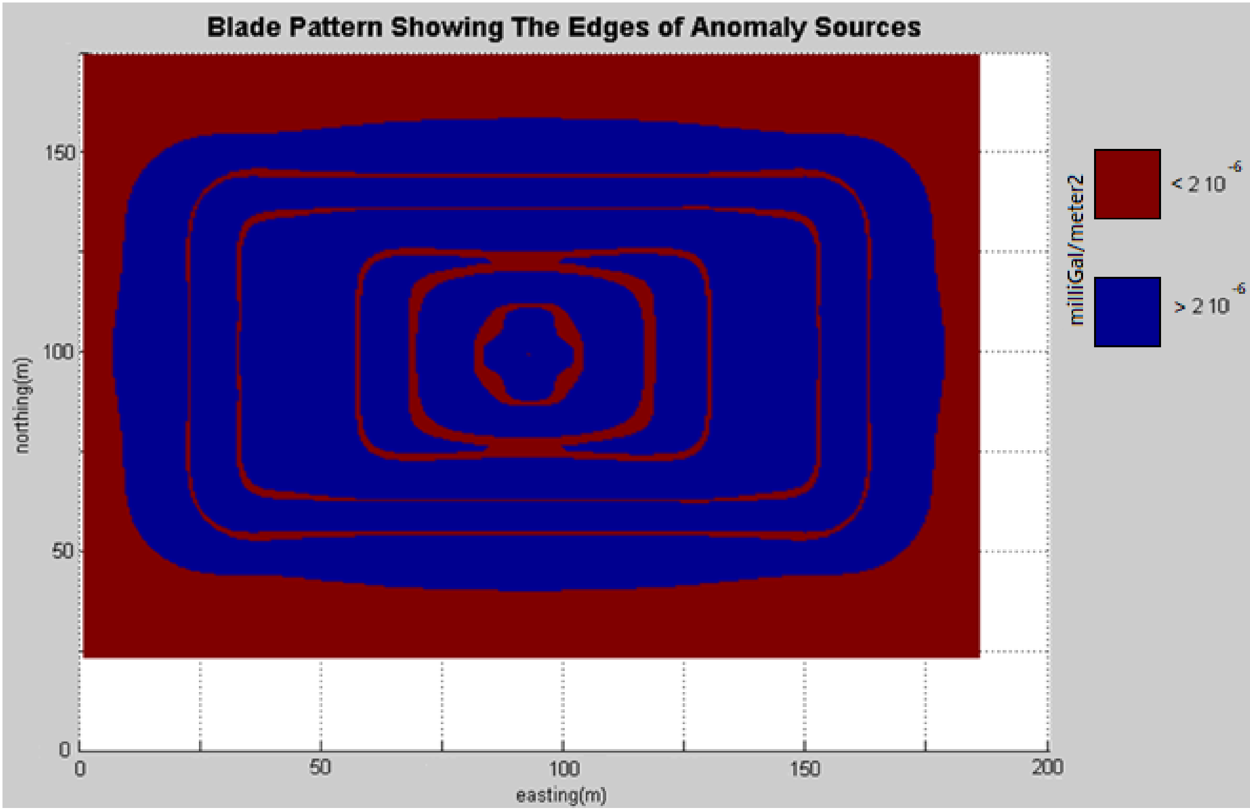

Figure 4. Blade pattern that shows sharp boundary of the buried temple model

Figure 4. shows that the red zone lines are the boundaries of the density contrast caused by the contact of the rock forming temple with the burial mass. The red zone at the outer shows zero values of SRD as a result of the long distance away from the anomaly source. Figure 3 and Figure 4 are exactly response of the same model, but there is a little bit displacement due to convolution effect.

Conclusion

The results of the tests of Radial Derivative on the synthetic show that the Radial Derivative is able to detect the boundaries in buried temples due to density contrast. Blade pattern of SRD is fairly good to show boundaries of density contrast. The advantage of Radial Derivative which is a horizontal derivative in the direction of radial compared to horizontal derivative in the only one direction is the ability to detect vertical boundaries of various anomalies due to large horizontal layers and capable of showing density contrast in almost all directions

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