Application of Genetic Algorithm Optimization and Least Square Method for depth determination from residual gravity anomalies

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ABSTRACT: This paper presents a combining method for depth determination of a buried structure from residual gravity anomalies along profile. Solving nonlinear equations using genetic algorithms till faces some problems. It often divert to the local solution, causing premature convergence. Also, depth determination by using least squares is low accuracy. Here, we present a method based genetic algorithm optimization and least squares to determination the model depth of simple causatives sources. Validity of this method is tested by applying synthetic data with random errors. This method has also been applied to real gravity data from USA. The depth obtained by the proposed method is found to be in a very good agreement with the depth obtained from drilling information.

Keywords: Simple Causative Sources, gravity data, genetic algorithm optimization, least squares approach.

INTRODUCTION

The problem of ambiguity in the interpretation of potential field data cannot be solved by any processing or interpretation technique. One of the most common problems encountered in gravity data inversion studies is how to improve the convergence and the geological reasonable. However, a unique solution may be obtained by incorporating some a priori information such as assigning a simple geometry to the causative source (Roy et al., 2000). Although simple models may not be geologically realistic, they are usually sufficient to analyze sources of many isolated anomalies. The optimization techniques based on genetic algorithms have opened up a new possibility for solving the inverse problem in a nonlinear context in gravity data applications (Chen, 2006). However, the inversion of gravity data using genetic algorithm still faces some problems. It often divert to the local solution, causing premature convergence. In this paper, we show how the idea of determination of depth using a new approach based genetic algorithm optimization and least squares approach for that takes advantage of global searching without initial parameters of genetic algorithm and convergence at accuracy of least squares. The validity of the proposed method is tested on synthetic data with noise and field example from the USA.

THE METHOD

Genetic Algorithm Optimization

Genetic algorithm is a search method developed by Holland (Holland, 1989), based on concepts of evolution introduced by Charles Darwin. Genetic Algorithm is designed to simulate the principle of the survival of the fittest. Genetic Algorithm incorporates several strategies from biological evolution, which shows remarkable success in producing organisms that efficiently exploit their environment. This is reproduced in genetic algorithms by three operators: selection, crossover and mutation. These are applied iteratively as the model population evolves.

Parameter representation: In genetic algorithms, each individual member of the population is represented in binary form or real values. In the parameter representation the lower and upper bounds of the parameter values must also be considered. These depend on the kind of problem under analysis and on the a priori information
Selection: Selection performs the transfer of the best solutions from one generation to the next. The main aim in this set of experiments was to collect a large number of different solutions which fit the data equally well.

Crossover: Crossover is the means of combining two individuals to produce the next generation by allowing for the exchange of genes.

Mutation: Mutation was implemented by randomly changing some parameter values in selected individuals. This is achieved by replacing each selected parameter value by a new value, randomly chosen within the restriction allowed in the parameter representation.

**Least Squares Approach**

The general gravity anomaly expression produced by a sphere, an infinitely long horizontal cylinder, and a semi-infinite vertical cylinder is given in Gupta, (1983) as

\[ V(X_i,Z,q) = \frac{KZ}{(X_i^2 + z^2)^q} \qquad i=1,2,3,\ldots,N \]  

In equation (1), Z is the depth, q is the shape factor, X is the position coordinate and K is Amplitude coefficient. Using normalized equation and Taking the logarithm of normalized equation, we obtain for all shapes:

\[ T(A) = qLN\frac{Z^2}{(Z^2 + A^2)}X_i = A \]  

(2)

Substituting equation (2) into logarithmic equation, we obtain the following nonlinear equation in the depth (Z):

\[ W(X_i,Z) = \frac{LN\frac{Z^2}{X_i^2 + Z^2}}{LN\frac{Z^2}{(A^2 + Z^2)}} \]  

(3)

The unknown depth (Z) in equation (3) can be obtained by least square. Setting the derivative of minimizing equation to zero with respect to Z leads to:

\[ T(Z) = \sum_{i=1}^{N} [L(X_i) - T(A) \ast W(X_i,Z)]W^*(X_i,Z) = 0 \]  

(4)

Where L(X_i) denotes the logarithm of the normalized observed gravity anomaly at X and W^* is dW/dZ. Equation (4) can be solved for Z using genetic algorithm for solving nonlinear equations.

**Combining GAO And LS**

Here, we illustrate how the idea of optimized gravity data using a new approach based on combining Genetic algorithm optimization and least squares method. This procedure is described with the aid of the schematic figure in Fig.1. We layout the optimized gravity data procedure which has four steps: (1) create a fitness functions in the light of the assumed system models (sphere, horizontal cylinder and vertical cylinder), (2) Product of initially data using genetic algorithm, (3) Take optimized data as initial data in least squares approach, (4) Finally determination of depth using GAO+LS method (figure 1)

**Synthetic Data**

Synthetic examples of spheres, vertical cylinders and horizontal cylinders buried at different depths (profile length 50 meter, density 600 Kg/m³, sample interval 1 meter) were interpreted using the GAO+LS method to determine depth. In all cases examined, the exact values of Z were obtained. However, in studying the error response of the GAO+LS method, synthetic examples contaminated with 5% random errors were considered. Following the interpretation scheme, values of the most appropriate model depths were computed and the percentages of error in models depths were plotted for comparison (figure 2)
Field Data

The Smoke Creek Desert, located approximately 100 km north of Reno near the California-Nevada border, is a large basin situated along the northernmost parts of the Walker Lane Belt a part of the Basin and Range physiographic province defined by diverse topographic expression and strike-slip faulting. Because geologic framework studies play an important role in understanding the hydrology of the Smoke Creek Desert, a geophysical effort was undertaken to help determine basin geometry, infer structural features, and estimate depth to basement.
The study area is bounded by Permian and Triassic met volcanic rocks and Cretaceous granitic rocks along the western margin of the Smoke Creek Desert. Triassic and Jurassic met sedimentary rocks and Cretaceous granitic rocks in the Fox and parts of the Granite Ranges along the eastern and northeastern margin of the Smoke Creek Desert (figure 4).

![Simplified geologic map of the Smoke Creek Desert and vicinity](image)

**Figure 4.** Simplified geologic map of the Smoke Creek Desert and vicinity (Ponce et al., 2006).
Gravity data for northwest Nevada and northeast California were derived from statewide compilations of Nevada and California and supplemented with over 587 gravity stations collected as part of the Smoke Creek Desert investigations. The study area includes 1,642 gravity stations that were reduced to a common datum using standard reduction methods that included terrain and is static gravity corrections (Blakely, 1995). The is static gravity corrections were based on an Airy-Heiskanen model of local is static compensation that enhances sources within the shallow- to mid-crust by removing long-wavelength variations in the gravity field inversely related to topography. Gravity values are expressed in milligals (mGal), a unit of acceleration or gravitational force per mass equal to $10^{-5}$ m/s$^2$. Gravity data were gridded at an interval of 400 m (1/4 mi) using a computer program based on a minimum curvature algorithm by Briggs (1974) and displayed as a color-contoured map (figure 5).

![Figure 5. profile AB and Residual gravity map of the Smoke Creek Desert and Vicinity.](image)

The interpretation yields to the estimation of the depth from the surface to the body as shown in Table 1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Depth (m)</th>
<th>% error in depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least square approach</td>
<td>214</td>
<td>2.72</td>
</tr>
<tr>
<td>Genetic algorithm</td>
<td>215</td>
<td>2.28</td>
</tr>
<tr>
<td>Genetic algorithm optimization and Least square approach</td>
<td>218.5</td>
<td>0.69</td>
</tr>
<tr>
<td>Drilling</td>
<td>220</td>
<td>-</td>
</tr>
</tbody>
</table>

The depth obtained ($z = 218.5$ m) in this case is found to be in very good agreement with obtained from drilling. Table 1 show that the highest value of error is obtained for the least square. The smallest value of error is obtained for GAO+LS. The evaluated curve by the proposed method is shown in Figure 6.
Figure 6. Residual gravity field anomaly over the two-dimensional Smoke Creek Desert and Vicinity. The evaluated curve by the proposed method is shown for a simple model.

CONCLUSION

From the previous experiments and analysis the following can be concluded: GAO exhibits rapid initial convergence without the need of set initial parameters, but its performance deteriorates as it approaches the desired global optimization solution. The diversity gradually diminishes in the process of search of global solution, GA divert to the local solution, causing premature convergence. GAO+LS procedure combines selected advantage from GAO and LS to achieve weak dependence on initial parameters, multi-point global searching, fast convergence and high accuracy. Therefore, this method maybe became a choice to solve the gravity inverse problem.

REFERENCES