Development and implementation of software to obtain the Resistivity Depth Image (RDI) using TEM data.

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Abstract

This paper aims to show and validate the result of synthetic data processed by the *ImagEM* software. This program is been developed by the Electromagnetic Interpretation Research Group of University of Brasilia. It processes time domain electromagnetic data for different platform systems like in loop. The program uses a simplified inversion by the secant method. This method has proven reliable for a qualitative analysis and it has proven very agile in its processing. It is based on the analysis of the secondary magnetic field to obtain as result an estimated of the depth of the conductivity target, its shape in two dimensions beyond of the conductivity relative values. So the *ImagEM* shows the Resistivity Depth Image (RDI). This software was initially developed in *MatLab* and its final version will be in *JAVA* so it can be used on Windows and Linux.

1.0 Introduction

Currently, geophysicists, geologists, engineers, hydrologists and other professionals and researchers in geosciences seek quantitative electromagnetic response to their questions. So geologists and geophysicists require updated software and easy to use, to maps and to model the Earth's subsurface.

The electromagnetics is one of the geophysical methods that have proved more efficient for modeling of the subsurface in a region exploit economically.

Some interpretation techniques have been developed, such as: imaging, modeling and inversion. Many researchers use these techniques to interpret information and use the Resistivity Depth Image (RDI) as a starting point for inversion of the misfit geophysical problems.

In this sense, the *ImagEM* generate the Resistivity Depth Image using time domain Electromagnetic data. This image of the region of the geological interest will provide information about the conductivity, the geometry of a body in the subsurface and its approximate depth. The software can be used by companies and university programs in Geophysics, Geology and Engineering. The program will facilitate the interpretation of geophysics in exploration for mineral resources, oil, engineering and geological exploration of regional and local levels.

2.0 Method

Part of the methodology applied was based on RAMPRES (Sandberg, 1988; von Huelsen, 2007; Von Huelsen et al. 2008), which calculates the apparent resistivity using the induced potential difference in a receiver coil, which is concentric in transmitter coil.

The *ImagEM* links two methods to process their data, a mathematical and physicist process. The mathematical method described below is known as secant method used to find the roots of polynomial equations. The physical method is based on the principles of the laws of Maxwell, the response of the secondary magnetic field as function of time is a necessary condition to obtain the RDI.

2.1 The secant method

The program *ImagEM* adopts, as the model of the convergence, the variation of the Newton-Raphson method (Press et al., 1992), also known as secant method. In the solution of polynomial equations is common to apply the computing the derivatives of the function, this calculation are often not easy, as in electromagnetic inversion. For cases like this, the derivative may be replaced by a quotient of the difference between the results of approximations of the roots on the own roots of polynomial functions (Chapra & Canale, 2002) as described below:

$$f^{'}(x) \approx \frac{f(x_n) - f(x_{n-1})}{x_n - x_{n-1}} \qquad (1)$$

The secant method circumvents the need to apply to the derivative; however, certain procedures must be followed: defining the function to be studied and the number of possible roots. From Equation 1 can be derived the Equation 2 find the roots (Chapra & Canale, 2002).

$$x_{n+1} = \frac{x_{n-1} \cdot f(x_n) - x_n \cdot f(x_{n-1})}{f(x_n) - f(x_{n-1})} \; para \;\; n = 1,2,3... \qquad (2)$$

Where: x_{n-1} and x_n are the approximations of the roots of the equation.
$f(x_{n-1})$ and $f(x_n)$ are the results for the x_n and x_{n-1} ,
n is the number of iterations to find the root.

After checking the possible amount of roots that can reach this function, you must define a range on the abscissa where one of the roots must be contained. This interval should not contain more than one root. As the secant method does not have an exact root, commonly forms part of an error, each iteration is made; its result is compared to the range of error. If the result is out of range, a new iteration will be performed if the result is within the margin of error; the last point is taken as the root of the function. However, it is possible that during the iterations is never found a root, and then the divergence occurs (Ruggiero, 1996). The Figure 1 illustrates the approach to find the root of the equation, according to the secant method.

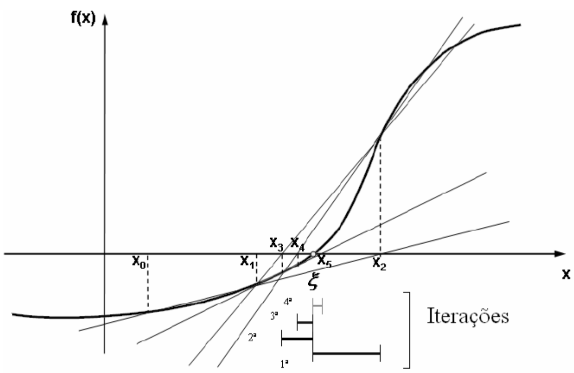

Figure 1: Chart showing the secant method. It´s mapping the secant between the points $P_0(x_0;f(x_0))$ and $P_1(x_1,f(x_1))$, is x_2, again applying the method in $P_1(x_1,f\ (x_1))$ and $P_2(x_2,f(x_2))$, is the value of x_3 and so on until the result is within the range pre-set (Ruggiero, 1996).

Another limiting factor is the number of iterations, which can be predetermined. The program performs a comparison of approximation of the root at each iteration calculated, if this value is relevant, the result converges and the program follows its normal flow. If this result does not match, a new calculation is made if the amount of calculations exceeds a specific value, the program then takes this value as the best found, and follows the script, considering that there was a convergence.

2.2 The physical method

The Figure 2 illustrates the survey aeroelectromagnetic, the primary magnetic field is generated by the transmitter coil and the receiver coil records the secondary field (following the laws of Maxwell). This arrangement can be considered the type concentric coils (in loop).

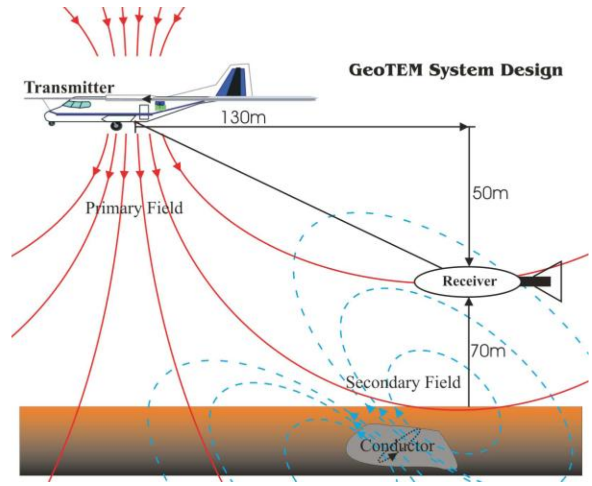

Figure 2: Drawing of representative aeroelectromagnetic survey using the system GEOTEM. Note the primary field generated by the equipment and the secondary field generated by the conductive body being picked up by equipment. Retrieved from Scrivens, 2009.

Houversten & Morrison (1982) evaluated the model based on the current maximum in a haft space for in loop. The behavior of the electromagnetic field generated by the transmitter coil, goes down as it interacts with the layers of the earth due to penetration of the signal, also described by Nabighian (1979).

The secondary field measured by the receiver coil, or the transient response is the ratio of potential difference by the current in a transmitter coil of electromagnetic equipment. Measures of the voltage *(U(t))* are calculated by the derivative of the magnetic field over time *(∂h/∂t)*, and was made by Newman et al.(1987):

$$U(t) = -\mu_0 \left(\frac{\partial h}{\partial t} \right) M \tag{3}$$

Where: *M* is the effective area of receiver coil (m^2).

μ_0 : electric permeability *(H/m²)*

This ratio captured by the receiver coil for each window of time may be related to a layered at different depths (Eaton, 1998; Wait & Hill, 1973).

Frischknecht & Raab (1984), based on the theory of Faraday's law show that the variation of the magnetic field generated by the variation of primary current induces a current in nearby conductors. In interactions with the early time the electric current is confined to the conductor surface and is normal to the field that produced it. When this current begins to be dissipated, causes a reduction of the magnetic field that generates current in the neighborhood, this behavior is explained by Figure 3.

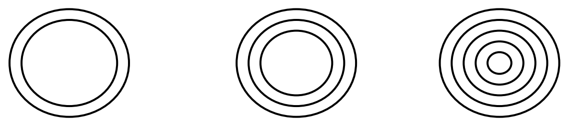

Figure 3: Sketch of current flow in a spherical conductor interacting after shutdown of the transmitter. Modified Von Huelsen, 2007

2.2.1 Calculation of Resistivity

The mathematical description of the resistivity (ρ_{ET}) according to the early time which is implemented in software is given by (Frischknecht & Raab, 1984):

$$\rho_{ET} = 6{,}3184\left(\frac{a_1^2 \cdot a_r}{v \cdot t^{2,5}}\right) \quad (4)$$

Where a_1 is the length of the transmitter, *t* is time in seconds, *v* is the impedance *(V/A)*, a_r is the effective area of the receiver. When this process is completed, the configuration of the induced current distribution is somewhat time invariant, also called late time. In this last stage we decrease the amplitude of the secondary field and resistivity (ρ_{LT}) is described by Frischknecht & Raab (1984).

When this process is completed, the configuration of the induced current distribution is more or less time invariant, also called late time. In this last stage we decrease the amplitude of the secondary field and resistivity (ρ_{LT}) is described by Frischknecht & Raab (1984).

$$\rho_{LT} = \frac{v \cdot a^3}{3a_r} \quad (5)$$

Where a is the radius of the transmitter.

Thus, using the electromagnetic coupling between the transmitter, receiver and target body, it is possible to measure the response of the secondary magnetic field. The body of higher conductivity sends a magnetic field of greater intensity and the duration of the electromagnetic interaction in receiver coil is greater (Frischknecht & Raab, 1984).

2.2.2 Calculation of Depth

There are different ways to calculate the depth through the electromagnetic field emitted by the target. In that program, we use the conductivity of the target, linked to the average decay time of each channel. One of the equations of depth of the program was proposed by Eaton (1998) adapted for the system to GEOTEM coils arranged on the same vertical axis.

$$d = 750\sqrt{\frac{t}{\sigma}}\left[1 - 5.67e^{-24\lambda}\right] \quad (6)$$

Where *t* represents time in seconds;
σ is the conductivity (S/m);

$\lambda = \sqrt{\frac{t}{\sigma \cdot h^2}}$;

h the height of the transmitter during the survey.
This parameter is still being tested in the software and should change.

3.0 Software *ImagEM*

As noted, the *ImagEM* calculations the depth and approximate resistivity to be used as a geoelectrical model for the observed electromagnetic field. For this calculation, the program has as input: a) the decay curves from the secondary field from the interaction of the subsurface, b) the average time of each corresponding channel off. The outputs of the program include conductivity, resistivity and depth.

The program was originally written in *MatLab*, because of the flexibility to implement their subroutines, its large library of functions that are available and easy to handle them. The same features are present on the *JAVA* platform, and there is a little difference between the syntax of the two platforms. To debug the program in *MatLab* is more dynamic and does not allow a syntax error or logic with the user interface, since the *MatLab* uses its own interface to run their programs.

The script program can be passed to the JAVA Net Beans (free version for Linux) without major changes to it's code, as most programs are made to the Windows operating system.

The spread of data processing is another strong point of the *ImagEM*. The configuration of the equipment used in field serves as input parameter for the software can process data not only for GEOTEM, as was previously planned, but for any equipment that uses the time domain.

Another important adjustment that is being done is the separation of the channels range for the early time and late time. Where the user chooses which he wants to process.

The final version of JAVA will have more screens friendly more interactivity with the user.

Finally, the software is being tested with synthetic data and then will be tested with real data.

3.1 Data and Results synthetic

We generated synthetic data using the direct model NLSOL (Nonlinear Least Square; Von Huelsen, 2007). The direct model was applied to a conductive body located at depth between *100* and *200* meters (*x* axis) at depth between 50 and *100* meters. The resistivity was *0.6 ohm m* body (Figure 4).

Later the decay curves obtained were subjected to processing the *ImagEM*, which resulted in values of resistivity and depth from the subsurface. These data were processed Geosoft™ and obtained the RDI by Kriging interpolation method with a mesh of 10m.

Figure 4 shows the result where there is a conductive body approximately 100 meters deep between the distances of 100 to 200m.

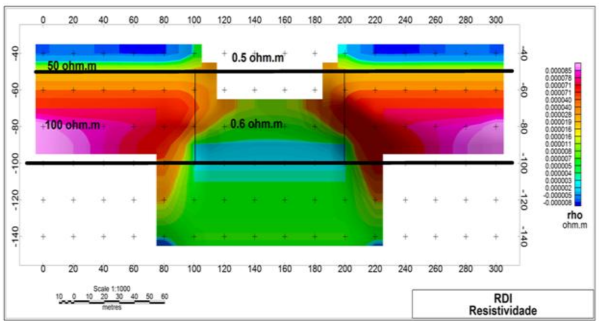

Figure 4: Initial synthetic model (values in omh.m, depth and boundaries indicated by black lines. The color ImagEM shows the result obtained by the image (RDI), identifying a central conductive body.

4.0 Conclusions

We conclude that the software *ImagEM* shows good qualitative results for the construction of 2D profiles of electromagnetic data in the time domain. We also saw that the method of secant is capable of reversing a fast and efficient search for the roots of the equations of resistivity. The equations of resistivity for the early and late time presented adequate results and the appropriate depths. The processing of synthetic data showed a great variation in the definition of lateral resistivity. The software *ImagEM* is concise and can be installed on the platforms Windows and Linux.

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