3-D INVERSION OF MT DATA USING MT3DINV-X SOFTWARE

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ABSTRACT

Essentially, the form of earth is 3-D so that 2-D earth model cannot be used to represents the earth in 3-D. Within magnetotelluric (MT) method, there are some problems when we use 2-D inversion result to represents the earth in 3-D as it need to define the geological strike direction, it is difficult to interpret the 3-D structure, and it has small number of degree of freedom. Therefore, MT 3-D inversion is very important tostudy and to apply in 3-D earth modeling. There are some benefits when we use 3-D inversion, as it can solve ambiguity, we do not make assumption of strike direction, high degrees of freedom, and spreading data location can be inverted easily without projecting data to some certain stright line. Recently, there are many 3-D inversion program, however the application is not userfriendly. Therefore, it is urgent to develop user friendly software to perform 3-D inversion. Now, it has been developed a 3-D MT data inversion software, namely MT3DInv-X. This software utilises algorithm of data space Occam's Inversion to perform 3-D inversion process effectively. Moreover, the software output can be exported into x, y, z, value data so that it can be visualized using 3-D visualization software previously developed, GeoSlicer-X.Fromthe 3-D visualization results, 3-D inversion result can be optimised to guide the subsurface interpretation.

Key words: Magnetotelluric, MT3DInv-X, MT 3-D inversion

INTRODUCTION

The subsurface objects are mostly in 3-dimension shape so that the modeling process approach should ideally use more 3-D model. In MT data, there are some problems faced when we use 2-D inversion approach to represent the 3-D earth, as it should make strike direction assumption, it is difficult to interpret 3-D structure, and it has small number of degrees of freedom. Based on the previous studies, it can be indicated if data has 3-D structure, 2-D inversion can contains error in interpretation process (Siripunvaraporn, 2011). Accordingly, 3-D inversion is important to apply in the 3-D earth modeling. There are many 3-D inversion algorithms of magnetotelluric (MT) data developed in recent decades (Siripunvaraporn, 2011). The main factor triggerring in the development of 3-D algorithms is the fact that 2-D interpretation still has an ambiguity. In addition, increasing use of MT data acquisition design encourages the use of 3-D algorithms. With 3-D inversion, data from spreading station positions can be inverted easily without data projection (Siripunvaraporn, 2011). Now, a user friendly 3-D inversion software has been developed by the Geothermal Laboratory of University of Indonesia in collaboration with PT. NewQuest Geotechnology, namely MT3DInv-X software (Daud et al, 2012). The software utilizes the algorithm of Occam's Inversion data space developed by Siripunvaraporn (2011). With this software, 3-D inversion process can be performed more effectively. The result of 3-D inversion in this software is integrated with GeoSlicer-X software (Daud and Saputra, 2010). The output of the MT3DInv-X can be exported into x, y, z, value data. The data can be used as data input in GeoSlicer-X to visualize the data in 3-dimension.

INVERSION

Inversion is mathematical approach which is used to perform fitting physical responses from model to observation (Baranwal, 2010). In other words, inversion is the mathematical tool which is used to convert from observation data to be subsurface model (Siripunvaraporn, 2012). There are three kinds of inversions which can be performed for MT data modeling, namely 1-D inversion, 2-D inversion, and 3-D inversion. One dimensional inversion can be applied with assumption that the earth is homogeneous laterally thus the subsurface resistivity value only varies in vertical orientation. Another case, 2-D inversion assumes that the earth varies to one lateral orientation and depth, while the other orientation is considered homogeneous. Whereas 3-D inversion is more representative with real earth condition with assumption that the resistivity value varies both laterally and vertically. From the assumption which is provided by each category, then it can be stated that 3-D inversion could represents the earth condition actually. However, 3-D inversion process takes much time and big CPU memory. However, when assumption of subsurface 2-D structure is valid, so 2-D inversion approach could be used as an alternative to obtain appropriate subsurface model (Baranwal, 2010).

INVERSION ALGORITHM

Inversion process which is performed in this method is divided into two phases. In the first phase, the inversion process will lead to desired RMS level with change λ. In the second phase, the inversion process will minimize norm model by change λ to find model with the smallest normalization while RMS is in desired level. There are two Occam's inversion categories, namely model space and data space (Siripunvaraporn, 2012).

- *Model space*

Basic principles in this method utilize linearization process using Taylor expansion as the following equation (1):

$$F(m_{k+1}) = F(m_k) + J_k(m_{k+1} - m_k) \qquad (1)$$

where $J_k = \dfrac{\partial F}{\partial m_k}$ is sensitivity matrix N x M

By using $\dfrac{\partial W}{\partial m} = 0$, the it will be obtained linear iterative equation (2):

$$m_{k+1} - m_0 = \left[\lambda C_m^{-1} + J_k^T C_d^{-1} J_k\right]^{-1} J_k^T C_d^{-1} d_k \qquad (2)$$

with:

$$d_k = d - F[m_k] + J_k(m_k - m_0) \qquad (3)$$

The excellence of this method is ability to achieve convergence in a few iterations. However, this method need great computation resource because the equation requires calculation of matrix inversion M x M $\left[\lambda C_m^{-1} + J_k^T C_d^{-1} J_k\right]$ and sensitivity matrix N x M $[J_k]$. Both of them need big CPU time and memory in each iteration process.

- *Data space*

Occam method creates modification by changing space model into data space so that the equation (2) changed to:

$$m - m_0 = C_m J^T \beta \qquad (4)$$

which β is N x 1 unknown coefficient vector. Equation (3) and F(m) put into objective equation to penalty functional in data space. The next, it is performed differential process data space penalty function towards β, then it will be obtained iterative equation as:

$$m_{k+1} - m_0 = C_m J_k^T C_d^{-1/2}\left[\lambda I + C_d^{-1/2} J_k C_m J_k^T C_d^{-1/2}\right]^{-1} C_d^{-1} d_k \qquad (5)$$

From the equation (5), it can be seen that data space method requires matrix inversion N x N $\left[\lambda I + C_d^{-1/2} J_k C_m J_k^T C_d^{-1/2}\right]$ and matrix N x M (sensitivity matrix Jk). By the data space approaching, matrix system M x M is replaced with N x N matrix. This causes all computation depends on number of data (N). Thus, CPU time and memory required is reduced significantly (Siripunvaraporn, 2012).

Based on its excellence, the algorithm used in the 3-D inversion software (MT3DInv-X) is Occam's inversion with data space method.

3-D INVERSION PROCESSING

3-D inversion processing depends on two things, namely data (N) and model (M). Generally, data (N) contains number of station (Ns), number of period (Np), and number of impedance responses (Nr). Whereas model (M) includes number of x-direction block (Mx), number of y-direction block (My), and number of z-direction block (Mz).

Three dimensional inversion process of MT data is performed by using MT3DInv-X (Figure 1). Algorithm used in this software is data space method (Siripunvaraporn, 2006). In general, input parameter which is prepared in this software is three points, namely data input, initial model, and inversion file (startup). Furthermore, before 3-D inversion is performed, software will input desired data file and model file.

MT data that is used in 3-D inversion process is real data in geothermal prospect areas. The first step is input edi file by using Load Edi File. Then the software will produce mat-file. The next, the mat-file can be opened by using Plotting MT Data Station. The next stage is setting the mesh grid parameter by determining block size, number of outside grid block, and factor coefficient outside the grid. The things to consider in mesh grid setting is required to set dense grid inside and loose grid outside (Figure 2). This is crutial stage because it is associated by initial model creating and memory which is used by computer while inversion running.
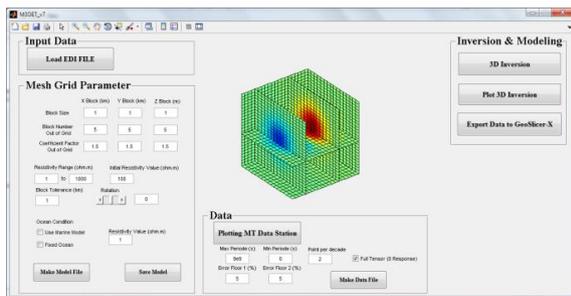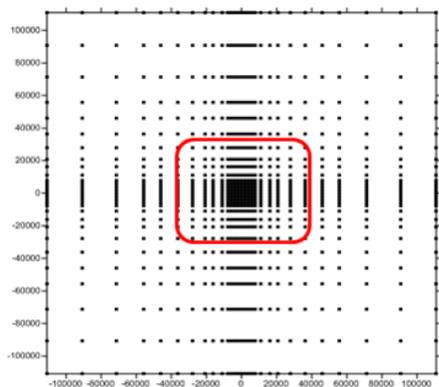

Figure 1. MT3DInv-X software visualization

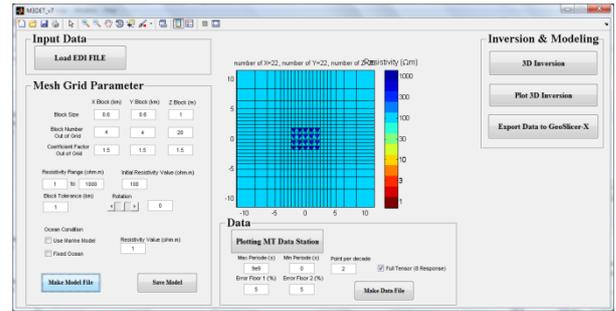Figure 2. Initial model grid visualization

Figure 3. Initial model result from MT3DInv-X software

Moreover, MT station position should be placed in the center of model and dense grid. Creation of initial model (Figure 3) should be well calculated and the distance between MT stations should also be considered. MT station should not be in boundary between one grid block and another grid block, but it should be inside one block grid. This is due to impedance data in one station can only be set for one block grid. After that, the initial model and data file should be saved. Furthermore, inversion process is performed by utilizing both files. The time required for performing the inversion process depends on the number of data, grid and computer specification. Usually, time required to do the first iteration tends to be faster than the next iteration.
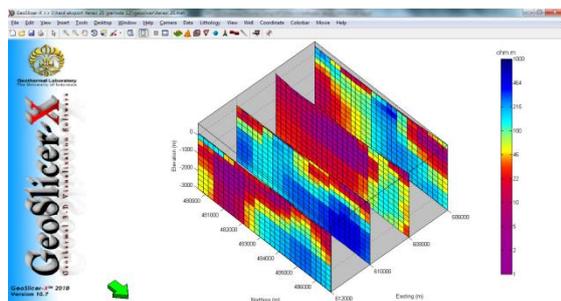
3-D Inversion Result

After performing 3-D inversion process, the output can be exported into data input of 3-D visualization software, GeoSlicer-X. Then, the data input is further processed. It will produce 3-D visualization as shown in Figure 4. From the Figure 4, it is shown that the high resistivity value (more than 500 ohm-m) is distributed at depth of more than 1000 m. It could be interpreted as heat source. While low resistivity is interpreted as clay cap. By analyzing the result of 3-D inversion, it can be obtained approriate subsurface information about geothermal system in certain area.
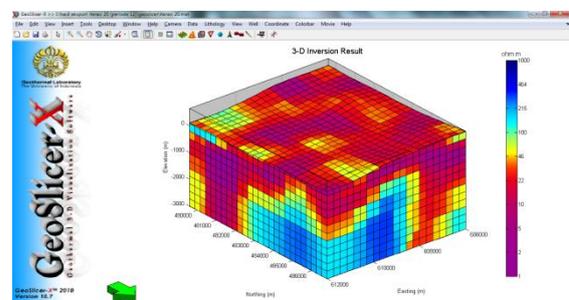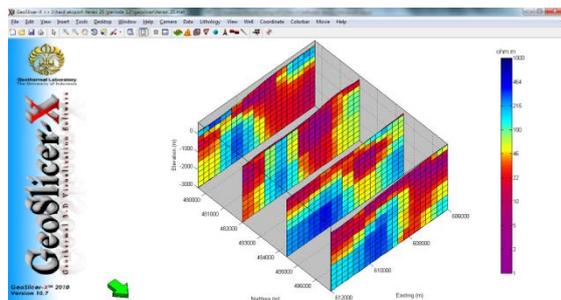

(a)
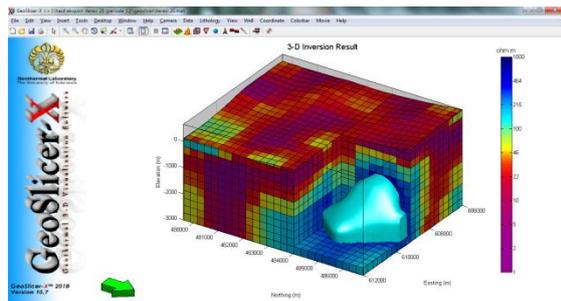
(b)

(c)

(d)

Figure 4. 3-D Inversion Results Visualized by
GeoSlicer-X software.

Conclusions

From software development which is performed, it
can be concluded that:
1. MT3DInv-X software can be used to facilitate
   in grid setting to perform 3-D inversion of MT
   data.
2. MT3DInv-X output can be integrated with 3-D
   visualization software, GeoSlicer-X.
3. The result of 3-D inversion of MT data
   visualized using the GeoSlicer-X software can
   provide information of the real condition of the
   subsurface.

Acknowledgments

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