VOXI Earth Modelling for Potential Fields

VOXI Earth Modelling is a cloud-based forward modelling and inversion service for potential (magnetic and gravitational) field data. It utilises a regularisation algorithm that incorporates patented technologies to provide users with specific computational and interpretive advantages over alternative potential field inversion algorithms. The purpose of this document is to summarize the general inversion methodology, describe unique, patented aspects of the service, and recommend how the user can reference the service and its components.

The service allows users to forward calculate the response of three-dimensional density, magnetisation vector, or magnetic susceptibility distributions, and allows the user to generate those same distributions, via inversion of the following types of data:

- Magnetic field data
- Gravitational field data
- Vertical gravity gradient data
- Bell Geospace gravity gradient system (FTG)
- Falcon gravity gradient system (AGG)

1. General Inversion Process

All potential field inversions within VOXI Earth Modelling use an algorithm that predicts a three-dimensional physical property distribution, i.e. a model, from a series of input observed potential field measurements. VOXI does this by employing Tikhonov minimum gradient regularisation (Zhdanov, 2002) to produce a model that conforms to a reference Earth model, and whose predicted response closely matches the input field data. The resultant model comprises a three-dimensional volume, discretized into a series of voxels, each containing a predicted physical property.

The generalised inversion process can be defined by the following expression:

$$\text{Minimize } \boldsymbol{\varphi_T = \varphi_d + \lambda\, \varphi_m} \text{ choose } \boldsymbol{\lambda} \text{ so that } \boldsymbol{\varphi_d \sim 1}$$

Where:

$\boldsymbol{\varphi_d}$ is the data norm

$\boldsymbol{\lambda}$ is the Tikhonov regularisation parameter

$\boldsymbol{\varphi_m}$ is the model norm

The inversion is an iterative process where the regularisation parameter and model norm are by default changed until the data norm is approximately 1 and the total objective function is minimized. The inverse problem given a concise representation of the forward problem as described in Ellis et al. (2012) is also applied to the modelling for conventional susceptibility and density.

Robert G. Ellis, Barry de Wet & Ian N. Macleod, 2012, Inversion of Magnetic Data from Remanent and Induced Sources, *ASEG Extended Abstracts*, 2012:1, 1-4, https://doi.org/10.1071/ASEG2012ab117

Tikhonov minimum gradient regularisation is described in the following book:

Zhdanov, M. S., 2002, *Geophysical inverse theory and regularization problems*: Elsevier Science Publishing Co., Inc.

2. Service-Unique Techniques

Several unique techniques are embedded into the inversion process within VOXI. These include:

- The Cartesian Cut Cell Method
- Iterative Reweighting Inversion (IRI) Focusing
- Magnetisation Vector Inversion

2.1.1. **Cartesian Cut Cell Method**

The Cartesian Cut Cell method allows inversions and forward calculations to utilise a relatively simple Cartesian voxel consisting of prismatic elements, which reduces computational complexity (and hence computation time), while at the same time allowing very accurate geometric representation of geological surfaces.

Embedding the method in the inversion and forward calculations eliminates well known artefacts that arise from representing topography with prisms of fixed vertical extent. The Cartesian Cut Cell method is applied for all forward and inverse potential field calculations in VOXI Earth Modelling.

The method is described in detail in this reference:

Robert G. Ellis & Ian N. MacLeod, 2013, Constrained voxel inversion using the Cartesian cut cell method, *ASEG Extended Abstracts*, 2013:1, 1-4, https://doi.org/10.1071/ASEG2013ab222

2.1.2. **Iterative Reweighting Inversion (IRI) Focusing**

IRI focusing is a patented technique that is applied by default during inversion. The technique consists of a sharpening function that includes an iterative inversion function that may include one or more weighting functions that are reweighted with each iteration. The user can define whether to apply this function to positive or negative anomalous zones of physical property, or both.

The sharpening function has the effect of producing more confined anomalous zones with a higher physical property contrast, which are more geologically reasonable than those predicted from default smooth model norms.

The technique is described in detail within this patent:

Robert Ellis, 2011. Method and system for modeling anomalous density zones in geophysical exploration. *US Patent 9372945*: filed August 31, 2011 and issued June 21, 2016. https://patents.justia.com/patent/9372945

2.1.3. **Magnetisation Vector Inversion (MVI)**

MVI is a patented inversion method that models the total magnetization vector, without any prior knowledge of the strength or direction of remanent or non-induced magnetisation. The method is different from conventional magnetic susceptibility inversion, which assumes that all magnetisation is aligned in the direction of the inducing field. In areas where non-induced magnetisation occurs, MVI provides a more robust solution.

The method is described in detail in the following papers and patent:

Robert G. Ellis, Barry de Wet & Ian N. Macleod, 2012, Inversion of Magnetic Data from Remanent and Induced Sources, *ASEG Extended Abstracts*, 2012:1, 1-4, https://doi.org/10.1071/ASEG2012ab117

Robert G. Ellis, 2012. Methods and systems for the inversion of magnetic data from remnant and induced sources in geophysical exploration. *US Patent 10534108*: filed August 28, 2012 and issued January 14, 2020. https://patents.justia.com/patent/9372945

3. Citing VOXI Earth Modelling

We recommend citing the following references for VOXI:

The VOXI Service:

Seequent Limited, 2020, *VOXI Earth Modelling Service*, http://www.seequent.com/voxi

Potential Field Inversion within VOXI:

Robert G. Ellis, Barry de Wet & Ian N. Macleod, 2012, Inversion of Magnetic Data from Remanent and Induced Sources, *ASEG Extended Abstracts*, 2012:1, 1-4, https://doi.org/10.1071/ASEG2012ab117

Service-Unique Techniques:

Please refer to the relevant section above and use the references and patents described within each.