geoconvention
Calgary • Canada • May 13-17 2019

Fusion of multi-physics data with machine learning independent component analysis (ICA) improves detection of geological features

Hassan H. Hassan and Serguei Goussev*

Multiphysics Imaging Technology, Inc.

Summary

Multi-physics data, such as airborne gravity and magnetics, has become standard in the oil-and-gas and mineral exploration. Their acquisition is time- and cost-effective in both the regional- and local-scale studies. Processing and interpretation provide the high-resolution information about the framework of structural discontinuities and concealed geological structures that is used for selecting the areas for application of much more costly and time-consuming seismic methods. Quite often, airborne gravity and magnetic surveys are flown over the same area or carried out with the same fixed-wing aircraft. Gravity and magnetic data are complementary to each other in their response to subsurface structural elements that create lateral density and magnetization contrasts and generate gravity and magnetic anomalies. Detection of anomalies is a function of sensitivity and resolving power that are different for the gravity and magnetic methods. For example, magnetic data are more resolving in detection of anomalies generated by structural discontinuities, such as faults and fracture zones, whereas the anomalous gravity data, being also responsive to faults and fractures, are more sensitive to the presence of the regional and local structures, such as anticlines, horsts, grabens, thrusts, etc. Accordingly, geological structures are partly shown on the obtained gravity image and partly on the magnetic image. Therefore, if we combine the gravity and magnetic data into a single fused image and use it in our interpretation flow, we would be able to detect geological structures more clearly and more efficiently than if we use images separately. Fusion combines images from different sources together to produce a combined image which provides the integrated visualization of information contained in each of the original images. Currently, several techniques are available for image fusing. In this study, we tested a robust technique based on the independent component analysis (ICA) to fuse the airborne gravity and magnetic images. ICA is a powerful machine learning multivariate statistical technique for performing the blind signal separation (BSS). It aims to separate the overlapping non-Gaussian and statistically independent component signals embedded in the gravity and magnetic images and fuse them together into a single image. We applied ICA fusion technique to the gravity and magnetic data acquired by the airborne magnetic and gravity gradiometry surveys over the McFaulds Lake area in Ontario, Canada. The preliminary results reveal a number of well defined geological structures that are not apparent on the individual gravity and magnetic images.

Introduction

It is becoming a standard procedure that with every gravity survey the magnetic data are acquired as well. Typically, gravity and magnetic data are displayed and analyzed separately, even though both are complementary to each other in their response to the same elements of geological structures such as faults and fracture zones. In order to make the gravity and magnetic interpretation better integrated, less subjective and more efficient, we made an attempt to combine two images into a single composite image using the fusion. There are several image fusion techniques available for this purpose (Hassan and Peirce, 2008; Goussev *et al*., 2009). For this study, we selected the machine learning approach which is based on the independent component analysis (ICA) to fuse the gravity and magnetic images. ICA is a powerful technique designed to extract a set of statistically independent components from a mixture of signals (Hyvärinen, 2013). We tested the capability of ICA algorithms to extract independent components, i.e. structural features, from the gravity and magnetic images and fuse them into a single image that might carry more information than the individual images. ICA-based fusing algorithm was applied to the Bouguer gravity and reduced-to-pole (RTP) magnetic grids obtained from the data acquired by the airborne magnetic and gravity gradiometry surveys over the McFaulds Lake area (aka, Ring of Fire) in Ontario, Canada. The airborne surveys were flown by Fugro Airborne Surveys in 2011 using the NW-SE oriented flight lines with 250 m spacing and orthogonal tie lines with 2500 m spacing at nominal terrain clearance of 100 m. Surveys were carried out on behalf of the Ontario Geological Survey and Geological Survey of Canada (OGS and GSC, 2011). Study area (Fig. 1) is considered to be one of the most prospective areas for the mineral and, possibly, oil-and-gas exploration. Geologically, the area overlaps the boundary between Archean basement rocks of the Superior Province and overlying Paleozoic sedimentary rocks of the Hudson Platform. It is underlain by the arcuate Neoarchean greenstone belt and sub-vertically dipping mafic and ultramafic intrusions, some of them are layered and crosscut the western portion of the belt (Cranston, 2010). Basement is mostly shallow. Regional geological mapping shows that the sedimentary rock cover is highly deformed by ultramafic igneous complexes toward the western end of the study area and combined with the Paleozoic sedimentary rocks in its eastern part. Magnetic patterns indicate the presence of complex rock formations composed of the volcanic and sedimentary belts between large expanses of granites and gneisses (Cranston, 2010).

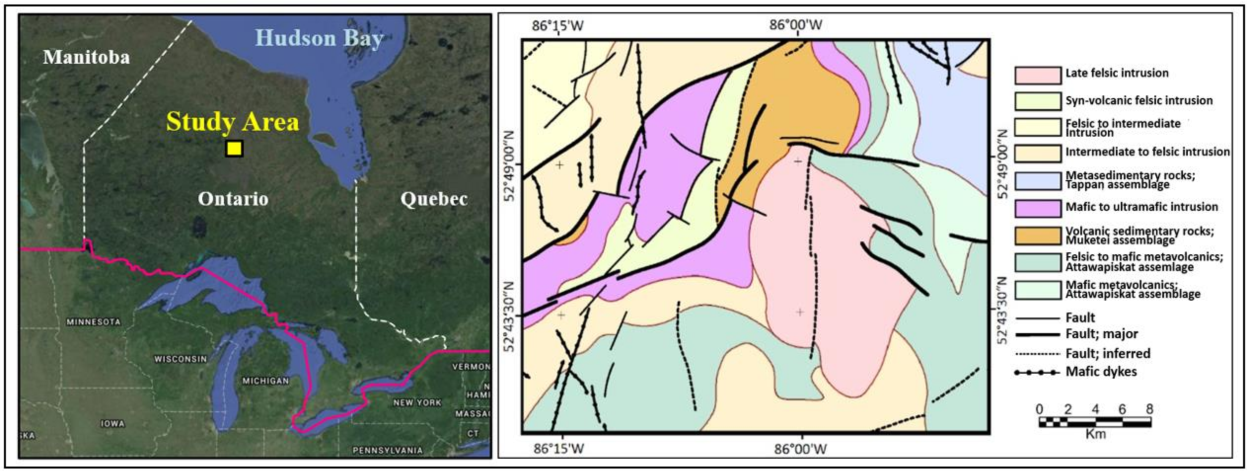

Figure 1. Index map (left) and generalized geology of the study area.

Methodology

The best way to describe the ICA technique is to refer to the 'cocktail party' example illustrated on Figure 2. Here, there are two people speaking simultaneously in a room and their voices ($\mathbf{S_1}$ and $\mathbf{S_2}$) are recorded by two microphones placed at different locations. We assume that two voices (**S₁** and **S₂**) are non-Gaussian and statistically independent. Their linearly mixed signals are recorded as **X₁** and **X₂** that can be expressed by the following linear equations:

$$\mathbf{x} = \mathbf{A}\mathbf{s}$$

$$\left\{\begin{matrix} x_1 = a_{11}s_1 + a_{12}s_2 \\ x_1 = a_{11}s_1 + a_{12}s_2 \end{matrix}\right\} \Rightarrow \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$$

Both, **A** and **s** are unknown and we try to estimate by ICA. The parameters (**a_{11}**, **a_{12}**, **a_{21}**, **a_{22}**) in matrix **A** are related to the distances between the microphones and the two speakers. ICA is aimed to estimate **A** and **s**, and obtain a de-mixing matrix **W**. For simplicity, we assume that the unknown mixing matrix **A** is square. The goal is to recover the original people's voices (**S_1** and **S_2**) when we are only given the observed data (i.e., **X_1** and **X_2**). After estimating the matrix **A**, we can compute its inverse **W** and obtain the independent component **u_1** and **u_2** (estimated sources) as follow:

$$\mathbf{s} \approx \mathbf{u} = \mathbf{A}^{-1}\mathbf{x} = \mathbf{W}\mathbf{x}$$

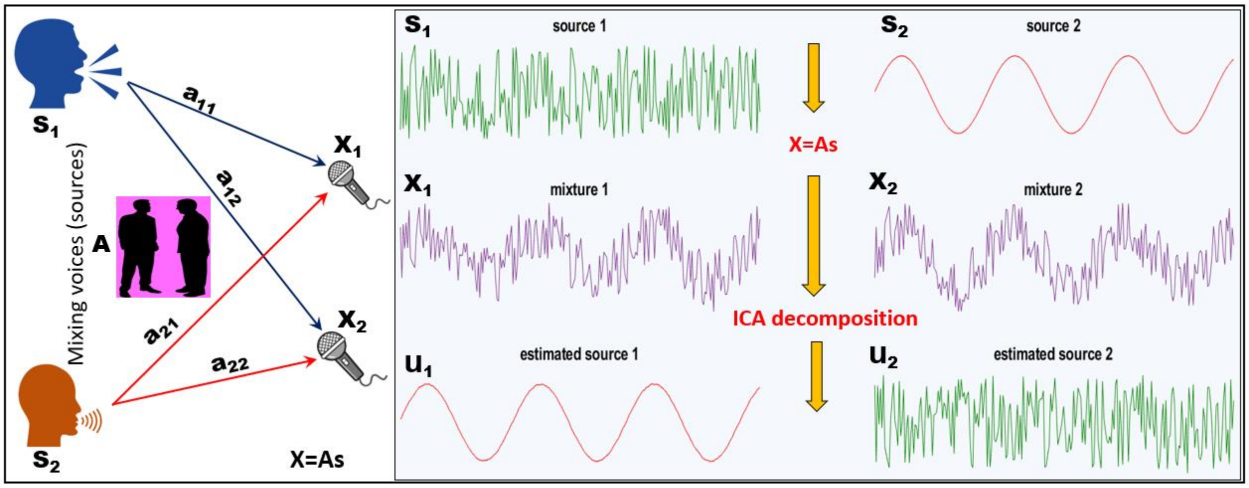

Figure 2. Explanation of ICA technique, using the cocktail party problem as an example.

Results

Prior to applying the ICA-based fusion to the data, both the gravity and magnetic images were subjected to two statistical transforms, centering and whitening, in order to run ICA correctly. Centering was carried out by subtracting the mean values (DC offset) from the gravity and magnetic images in order to make their new mean values equal to zero. Whitening was performed in order to remove any correlations existing in the data. This was done by applying principal component analysis (PCA) to the gravity and magnetic data. In accordance with Poisson theorem, the reduced-to-pole magnetic field (Fig. 3c) is equivalent to the first vertical derivative of Bouguer gravity (Fig. 3b), so that we used the first vertical derivative gravity image instead of Bouguer gravity image (Fig. 3a) for the fusion. Result of the ICA-based fusion is shown on Figure 3d. In comparison to the original gravity and magnetic images, it highlights a number of significant geological features that are not clearly defined on the individual gravity and magnetic images, such as the NNW-trending structure in the NE corner, WNW-ESE and SW-NE trending structures in the central and other parts of the area.

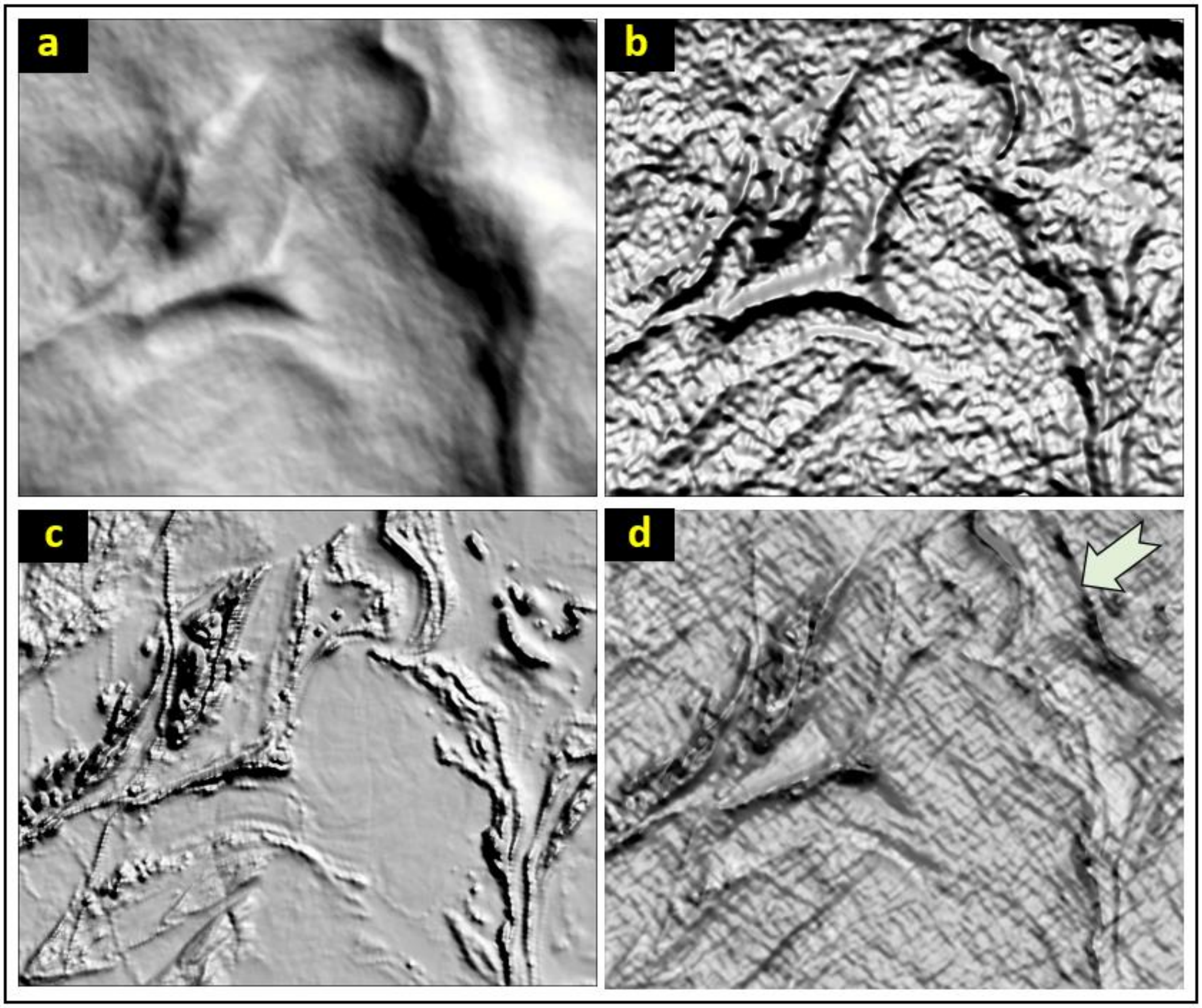

Figure 3. Gravity and magnetic images used in this study: (a) Bouguer gravity; (b) First derivative of Bouguer gravity; (c) reduced-to-pole total magnetic field; (d) fused gravity and magnetic image.

Conclusions

In this study, we applied the ICA-based fusion technique to the gravity and magnetic images obtained from the data acquired by the airborne magnetic and gravity gradiometry survey. The aim was to extract the most important geological features from two images and fuse them into a single image of the integrated information content for more objective and efficient analysis of detected anomalies and their interpretation. Fused image reveals a number of geological structures that are not clearly defined on the individual gravity and magnetic images. We believe that this technique could be even more efficient in fusing the high-resolution images traditionally obtained from the individual components of the full tensor gradient (FTG) data.

References

Cranston, D., 2010, “Ring of Fire” investment opportunities in Ontario’s far North; Ontario Ministry of Northern Development Mines and Forestry, 25p.

Dyer, R.D., and Burke, H.E, 2012, Preliminary results from the McFaulds Lake (“Ring of Fire”) area lake sediment geochemistry pilot study, northern Ontario; Ontario Geological Survey, Open File Report 6269, 26p.

Goussev, S.A., Hassan, H.H., Shield, G.W. and Cokinos, J.S., 2009, Fusion of enhanced gravity and magnetic signatures for continental-oceanic boundary (COB) mapping: offshore Gabon example; SEG Convention, Workshop Poster, Houston.

Hassan, H. H. and Peirce, J. W., 2008, Fusion of airborne gravity and magnetic images for improved detection of structural control; 2008 CSPG-CSEG-CWLS Convention, Calgary, Alberta, 4p.

Hyvärinen, A., 2013, Independent component analysis: recent advances; Philosophical Transactions of the Royal Society of London, A371, 20, 110-534.

Ontario Geological Survey and Geological Survey of Canada, 2011, Ontario airborne geophysical surveys, gravity gradiometry and magnetic data, grid and profile data (ASCII and Geosoft formats) and vector data, McFaulds Lake area; Ontario Geological Survey, Geophysical Data Set 1068.