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Filter assisted bi-dimensional empirical mode decomposition: a hybrid approach for regional-residual separation of gravity anomaly

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ABSTRACT

Adequate separation of regional-residual components from observed gravity anomaly is always a challenging task in gravity interpretation. Several techniques have been developed for effective regional-residual separation, however, no single approach can perfectly accomplish the job. In this work, a hybrid approach has been proposed with an objective to enhance the performance of Bi-dimensional Empirical Mode Decomposition (BEMD) in decomposing gravity anomaly by jointly employing low pass filter and BEMD. The paper discusses the efficacy of this hybrid approach in gravity anomaly separation from noisy synthetic and field data. Synthetic studies involving forward modelling of asymmetrically placed shallow and deeper spherical bodies with added Gaussian noises of different levels demonstrate that the proposed approach is more efficient in separating the regional-residual components from observed gravity anomaly compared to the individual application of filtering or BEMD. It has an added advantage of suppressing the unwanted noises significantly. After successful test with synthetic data the proposed approach has been applied to field data and satisfactory results are obtained. Thus, the proposed hybrid approach is more effective in delineating gravity signature related to complex near surface features even from noisy gravity data.

1. Introduction

Observed gravity anomalies at different surface locations are due to the superposition of anomalies associated with lateral and vertical mass (density) distribution of geological features at different depths. Separation of gravity anomalies caused by widespread deep seated (regional) geological features from that due to shallow subsurface (residual) mass distribution is a crucial step in quantitative interpretation of gravity anomalies. This can be accomplished using various standard approaches, e.g.,graphical smoothing (Telford et al., 1990), second vertical derivative (Henderson and Zietz, 1949), trend surface analysis (Agocs, 1951; Merriam and Harbaugh, 1964; Beltrao et al., 1991; Roach et al., 1993), filtering (Griffin, 1949; Zurflueh, 1967; Spector and Grant, 1970; Pawlowski and Hansen, 1990) to name a few. In recent years, several new approaches have been introduced, e.g.,based on 3D inversion algorithm (Li and Oldenburg, 1998), Wavelet and spectrum analysis (Fedi and Quarta, 1998; Xu et al., 2009) etc. However, the separation of regional and residual components is a difficult task and it does not have an absolute solution. Thus, there always remain scope for improvement, e.g.,the problem of spectral overlapping of regional and residual anomalies in Fourier domain spectral filtering has been overcome by the use of wavelet domain decomposition (Zhang et al., 2009). Wavelet analysis can simultaneously provide the time and frequency information of a signal, thereby capturing the non-stationarity aspects of the data. However, the requirement of a predefined basis wavelet for all data throughout a signal makes wavelet analysis inefficient in capturing the non-linear behaviour of the data (Huang et al., 1998; Hassan and Pierce, 2008). These methods are unable to adaptively handle the input signals and are, therefore, not suitable for handling data characterized by both non-linear and non-stationary nature (Huang et al., 1998; Hassan, 2005; Huang, 2006). Therefore, researchers have very recently applied new self-adaptive techniques, namely, Empirical Mode Decomposition (EMD) and its variant in two dimensions, i.e.,Bi-dimensional Empirical Mode Decomposition (BEMD) to satisfactorily decompose the non-stationary and non-linear geophysical data into inherent components. The superiority of these techniques is a result of their adaptive nature while handling the data and having no prior basis for the decomposition process (Huang et al., 1998, 2003). EMD decomposes an original one dimensional signal into constitutive components termed Intrinsic Mode Functions (IMFs) and can express the original signal as a sum of IMFs. Extending the concept of EMD in two dimension, the BEMD was developed; and like EMD it also decomposes a two dimensional signal into constitutive Bi-dimensional Intrinsic Mode Functions (BIMFs) (Huang et al., 2010). One major disadvantage of this technique is the non-continuity of constitutive signals and mixing up of the energy

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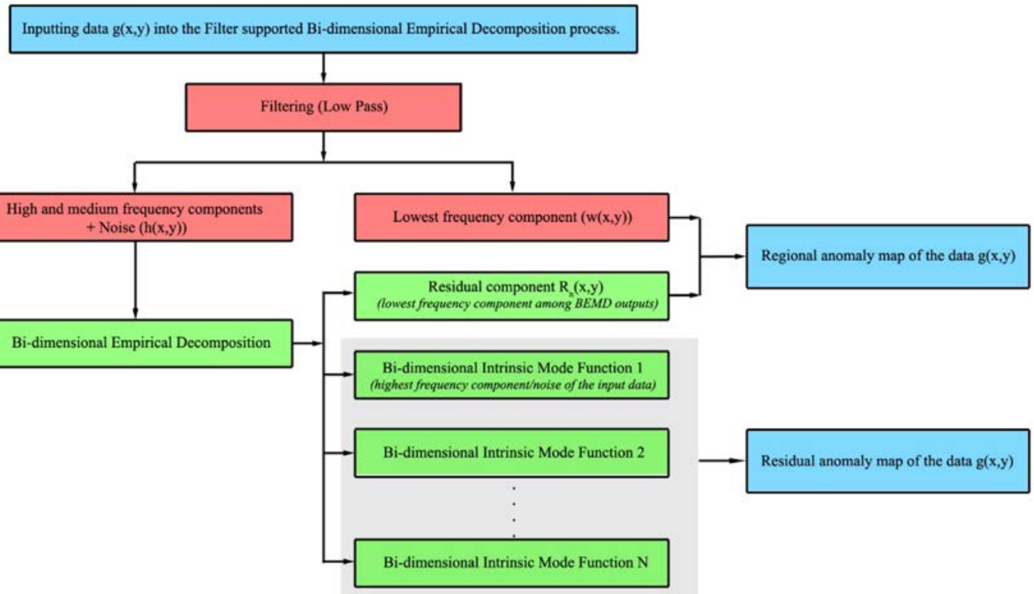

Fig.1. Flowchart illustrating the workflow of the proposed filter assisted Bi-dimensional Empirical Mode Decomposition approach.

of more than one components in a single IMF/BIMF which restrict its application to the analysis of scatter data (Hou et al., 2012; Al-Rahim, 2016). The repercussions of this phenomenon in gravity interpretation is the masking of shallow small scale features by larger and deeper ones. Hence to address this problem, an attempt has been made to assist BEMD with low pass filtering approach. The concept behind this is that the low pass filter can be first used to filter out the long wavelength (regional) component and the remainder (i.e.,high frequency part of the signal with noise) will be used as input signal for the BEMD process. The adaptive nature of BEMD makes it useful for separating the short wavelengths (residual) components from the other unwanted high frequency noises which may remain/arise due to imperfect data acquisition/processing. This workflow also reduces the scope of energy mixing in the BIMFs.

Thus, the present work prescribed a hybrid approach called filter assisted BEMD as an alternate regional-residual separation approach for gravity anomaly decomposition. In this approach, low pass filter and BEMD has been utilised simultaneously such that high frequency output of filter acts as input for BEMD. This resulted in an enhanced regional-residual separation from the observed gravity anomaly by surpassing the shortcomings of the individual constituent approaches. The proposed approach has been tested with noisy synthetic gravity data (to mimic the real data) generated from the synthetic model considering shallow and deep seated spherical bodies added with Gaussian noises using a computer program developed in MATLAB. In this model, the shallower bodies of different sizes were kept asymmetrically in the grid and at different depths mimicking a complex geological scenario. In contrast to some previous works regarding the demonstration of potential field data decomposition (e.g.,Agarwal and Sivaji, 1992; Li and Oldenburg, 1998; Xu et al., 2009; Guo et al., 2013; Obasi et al., 2016; Gabtani and Jallouli, 2017), we have checked the robustness of the proposed method with varying noise levels as well as with synthetic data generated from a complex model. The study shows that the proposed hybrid approach is more efficient in separating the desired components compared to the individual application of filtering or BEMD approach. The improvements are both qualitative, preserving the shape and texture of the original signal as well as quantitative as shown through the calculated RMS error (RMSE). The proposed workflow is then applied to field dataset and the results are discussed.

2. Methodology

In the present work, low pass filter and BEMD has been applied jointly with an objective to separate the low frequency regional component first using a low pass filter and the remaining high frequency residual (with noise) component is then taken as input for further processing with BEMD(Fig. 1). A MATLAB code has been developed to perform this routine. Therefore, the methodology of the present work can be divided into two main parts: filtering and application of BEMD.

2.1. Filtering

In this work, a 2D isotropic Gaussian function has been utilised for filtering. In frequency domain, this 2D function centred on the wave vector $\mathbf{k_0}$ can be represented as (Audet and Mareschal, 2007):

$$\psi(\boldsymbol{k}) = e^{-\frac{1}{2\sigma^2}|\boldsymbol{k}-\boldsymbol{k_0}|^2} \tag{1}$$

It acts as low pass filter with a small k_0 value. To filter the low frequency regional anomalies a proper standard deviation (σ) value has to be chosen as the bandwidth and the centre frequency decreases with increasing the value. The low pass filtering has been performed in the frequency domain following the steps given below:

(a) Compute the Fourier transform $G(\boldsymbol{k})$ of the input gravity anomaly $g(\boldsymbol{x})$ and shift in such a way that the low frequency anomalies concentrate at the centre.
(b) Multiply the gravity anomaly spectrum with the eq. (1) in frequency domain and calculate $W(\boldsymbol{k}) = G(\boldsymbol{k}) \times \psi(\boldsymbol{k})$, to filter out the higher frequency anomalies. As the mean of the filter is

Table1
Model parameters for the synthetic model.

Body No. andtypeof anomaly	Xco-ordinate (m)	Yco-ordinate (m)	Depth of the centre of the body (m)	Radius of the body (m)	Density contrast (inkg/m^3)
1 (Res.)	20	180	40	12	2000
2 (Res.)	100	20	50	15	2000
3 (Res.)	180	150	30	10	2000
4 (Reg.)	100	−700	350	120	2000