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Hurst Exponent-driven magnetotelluric signal noise suppression using adaptive mode decomposition methods

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Abstract

The magnetotelluric (MT) method is a passive geophysical technique used to image the electrical resistivity structure of the Earth. MT signals are usually contaminated by various types of noise. The quality of the impedance tensor estimate is degraded by noise, which in turn influences subsurface models. In this paper, we present a noise suppression scheme based on the Hurst exponent by applying adaptive mode decomposition methods to MT signals. These methods are, Empirical Mode Decomposition (EMD), Ensemble Empirical Mode Decomposition (EEMD), Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN), and Improved CEEMDAN (ICEEMDAN). Each method decomposes the noisy MT signal into a set of intrinsic mode functions (IMFs), also called modes or components. We then compute the Hurst exponent for each mode; modes with low Hurst exponents, are considered noise-dominant, and those with high Hurst exponents, are classified as signal-dominant. The noise-suppressed or denoised signal is reconstructed by summing only the signal-dominant modes. We tested this approach on real MT field data collected from the Dharwar Craton, Karnataka State, and compared the performance of all four methods using performance indicators, which include signal-to-noise ratio and correlation coefficient. Results show that the Hurst exponent is an effective criterion for identifying and separating signal from noise in MT data. Among the four methods, ICEEMDAN provides the best noise suppression performance. This study offers a practical, adaptive approach to remove different types of noise from the MT signal.

Keywords: Magnetotellurics, Dharwar Craton, Hurst exponent, Empirical Mode Decomposition, EEMD, CEEMDAN, ICEEMDAN, Noise suppression

INTRODUCTION

The magnetotelluric (MT) method is a geophysical exploration technique. To study the electrical resistivity of the Earth's subsurface, it uses natural variations in the electromagnetic (EM) field. The theoretical basis of the MT method was first proposed by Tikhonov (1950), and later, Cagniard (1953) developed the practical method. Since then, the MT method has been widely used in mineral exploration, geothermal studies, investigations of crustal structure, and hydrocarbon exploration.

At the Earth's surface, MT signals are measured as time series of electric and magnetic field components. The electric field is measured using grounded electrodes, and the magnetic field is measured using induction coils or fluxgate magnetometers. The impedance tensor is estimated by the ratio of electric to magnetic fields in the frequency domain. The impedance tensor is then used to calculate apparent resistivity and phase, which are the primary data used for subsurface imaging.

However, MT signals are mostly contaminated by noise from different sources. Cultural noise from power lines, electric fences, and railways is common in many areas due to urbanisation. The data also gets distorted by near-field source effects. Due to instrument vibrations, random noise from wind, and electronic circuits noise degrades signal quality (Chave and Jones, 2012). This noise is a major problem in MT data processing, which leads to biased impedance estimates and distorted apparent resistivity and phase curves. This, in turn, produces unreliable inversion models.

To handle noise in MT data, different techniques have been developed, such as the remote reference method, where a reference station is used to remove correlated noise (Gamble et al., 1979). Techniques such as robust processing, use statistical methods to downweight noisy data segments (Egbert and Booker, 1986). Fourier-based filtering methods are used to remove narrowband noise such as power line harmonics. However, these methods have limitations, while the remote reference method requires an additional station. Robust processing may not remove strong noise completely, and the Fourier-based filtering method assumes stationarity, which MT signals do not satisfy.

In recent years, data-driven decomposition methods have drawn attention in digital signal processing. Huang et al. (1998) proposed the Empirical Mode Decomposition (EMD) method, which doesn't require a predefined basis; it decomposes a signal into a set of Intrinsic Mode Functions (IMFs). This property makes it an appropriate technique for non-stationary and non-linear signals like MT data. However, there are a few shortcomings, like EMD suffers from mode mixing, which means that a single IMF may contain oscillations of very different frequencies.

To address the mode mixing problem, Wu and Huang (2009) proposed a technique, the Ensemble EMD (EEMD). In this method, before decomposition, white noise is added to the signal, and the results are averaged over many trials. Torres et al. (2011) further improved this approach with Complete Ensemble EMD with Adaptive Noise (CEEMDAN). Later, Colominas et al. (2014) proposed the Improved CEEMDAN