International Journal of Applied Earth Observation and Geoinformation 58 (2017) 134–144

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Selecting optimum base wavelet for extracting spectral alteration features associated with porphyry copper mineralization using hyperspectral images

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ARTICLE INFO

Article history:
Received 23 June 2016
Received in revised form 2 February 2017
Accepted 4 February 2017

Keywords:
Base wavelet selection
Hyperspectral images
Porphyry copper deposits
Wavelet transform

ABSTRACT

Extracting a set of meaningful spectral features could enhance the classification performance. This is particularly important in hyperspectral images where the dataset are very large and time consuming to process. Wavelet transform as a powerful decomposition tool in both low and high frequency components could play an essential role in extracting spectral features of target minerals. Selecting the optimum base wavelet is an important step in wavelet transform. In this research, two criteria to select optimum base wavelet were implemented on three wavelet series including Daubechie (db), symlet (sym) and coiflet (coif). Energy criterion involves entropy factor and energy-to-Shannon entropy ratio while matching shape criterion operates according to correlation coefficients. High ranking base wavelets in both energy and shape criteria, coif1, db3 and db7, are recommended to be utilized in hyperspectral image classification. Neural Network technique was used for classification and trained by means of mineral spectral features related to typical porphyry copper deposits. Non-Linear wavelet feature extraction was employed to select the efficient features as input data. The study area covered by Hyperion data contains two well-known porphyry copper deposits, Darrehzar and Sarcheshmeh, located in the Iranian copper belt. Based on classification error matrix, it is concluded that db7 through 12 selected features exhibits the maximum consistency with the field measured data and can be recommended as an appropriate base wavelet for detecting porphyry copper deposits.

1. Introduction

Selecting the base wavelet is a major concern in using wavelet transform in most applications, because different results may be produced by applying different base wavelets on the same signal. In the field of mineral exploration, the default base wavelet commonly used in other applications has been adapted and no attempt in selecting the optimum base wavelet has been made. Hence, this research aims at selecting optimum base wavelet as a reference wavelet capable of extracting spectral features hidden in satellite images,

Remote sensing, as an open research area, utilizes various challenging concepts such as spectral analysis, segmentation, and classification in a variety of applications. Hyperspectral Imagery acquires images in many narrow, contiguous spectral bands that create a continuous radiance for reflectance spectrum. Many materials are recognized by the position, strength (depth), and shape of their absorption features. These unique spectral signatures in combination with very fine spectral resolution of hyperspectral images provide a powerful means to discriminate different materials on earth surface (Matteoli et al., 2010).

The complexity and high dimensionality of hyperspectral data make the classification procedure more difficult, thereby necessitating the application of more accurate classifying methods. Increasing the feature space in hyperspectral data increases the number of required training samples to reach a more precise classification result. A set of meaningful spectral features extracted from the original hyperspectral data could improve the performance and speed of classification by avoiding the redundant information without eliminating significant information. There exists a number of methods for feature extraction and the dimensionality reduction of hyperspectral data such as the principal component analysis, dis-

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http://dx.doi.org/10.1016/j.jag.2017.02.005
0303-2434/

criminant analysis, decision boundary, projection pursuit, wavelet transform, and so on (Hsu and Tseng, 2000; Hsu et al., 2006)

Wavelet transform, as a popular time-frequency analysis method, has been widely implemented in various fields including science, medicine, engineering and finance. In the field of signal and image processing, the wavelet transform has also been successfully used in denoising(Chen and Qian, 2011; Parrilli et al., 2012), image classification (Shankar et al., 2007; Oussar et al., 1998), image fusion (Amolins et al., 2007; Yu et al., 2012) and features extraction (Hsu and Tseng, 2000; Hsu et al., 2006; Huang and Zhang, 2012; Hsu, 2007). Using wavelet transform, the local spectral variation of a hyperspectral curve in different spectral bands at each scale (or frequency) can detect significant information from hyperspectral image.

Selecting the best base wavelet is an important issue in using the wavelet transform for various applications because different base wavelets applied on the same signal may produce different outputs. Various methods have been introduced to select the best base wavelet. Flanders (2002) investigated different mother wavelets on EMG signal based on similarity criteria and found that db2 was the mother wavelet most similar to the EMG signal. Fu et al. (2003) proposed bi-orthogonal wavelet as the best mother wavelet to separate the surface profiles into their multi-scale representations based on wavelet properties. Safavian et al. (2005) showed that db4, coiflet, and b-spline are suitable for detecting power system transients. Bedekar et al. (2005) used Shannon entropy to choose the best mother wavelet for radio-frequency intravascular ultrasound (IVUS) data decomposition and found db3 as the optimal wavelet for such tasks. Tsui and Basir (2006) used entropy criteria to select the most suitable mother wavelet for automatic ultrasound non-destructive foreign body (FB) and they found that bi-orthogonal wavelet is the best mother wavelet for FB. Rehman et al. (2014) investigated the performance of several wavelet base functions in SPIHT coding. The results showed that the use of biorthogonal wavelets bases is better than orthogonal wavelet bases. Out of entire biorthogonal wavelets, the biorthogonal 4.4, shows good results in SPIHT coding. He et al. (2015) studied a novel comprehensive entropy criterion, E_{com} criterion, based on multiple criteria related to entropy and energy to search for an optimal base wavelet for a specific ECG signal. The E_{com} was compared with other criteria through four filtering performance indexes. Results showed the wavelet identified by the E_{com} to have achieved the best filtering performance compared with other comparative criteria. Al-Qazzaz et al. (2015) performed a comparative study to select the efficient mother wavelet (MWT) that would optimally represent the signal characteristics of the electrical activity of the human brain through electro-encephalography (EEG). They grouped these electrodes into five recording regions corresponding to the scalp area. Through ANOVA analysis, the best results were obtained using “sym9” across the five scalp regions. Garg (2016) introduced a novel automatic wavelet function selection algorithm called MWS algorithm. That was implemented by fusing GA and ANOVA appropriately to find the optimal wavelet function from a set of wavelet functions in the wavelet library. This algorithm was applied on different biomedical datasets. The results revealed that the solutions of automated algorithm are consistent with the manual selection of wavelet functions.

Detecting hydrothermally altered minerals by their spectral features is an active research area in mineral exploration using remotely sensed imagery. Most of the known porphyry copper deposits are characterized by their well-developed hydrothermal alteration zones which are large enough to be detected and mapped using remote sensing data (Honarmand et al., 2013).

The objective of the current study is to find the optimum base wavelet for extracting main spectral features of alterations in mineral mapping especially in porphyry copper mineralization to be used in classifying hydrothermally altered minerals. Selecting a base wavelet from a widely used wavelet family of functions is investigated by energy and shape matching criteria. The method for scoring the employed wavelet in current work to select optimum base wavelet has been adapted by the authors for the first time in this field. Discrete Wavelet Transform (DWT) has been implemented to decompose the spectrum of Hyperion satellite imagery in order to extract the most important spectral features.

2. Materials and methods

2.1. Wavelet transform

Wavelet transform provides an estimate of the local frequency content of a signal by signifying the data through a family of wavelet functions at different scales or resolutions (Hsu, 2007).

The wavelet transform of signal $x\ (t)$ can be written as:

$$wt(s,t) = \langle x,\ \psi_{s,\tau} \rangle = \frac{1}{\sqrt{s}} \int_{\infty}^{\infty} x(t)\, \psi^* \left(\frac{t-\tau}{s} \right) \ dt \qquad (1)$$

Where, $s>0$ denotes the scaling parameter, which determines the time and frequency resolutions of the scaled base wavelet $\psi(t-\tau/s)$. The specific values of s are inversely proportional to the frequency. The symbol τ is the shifting parameter, which translates the scaled wavelet along the time axis. The symbol ψ^* represents the complex conjugation of the base wavelet ψ (Gao and Yan, 2011).

Wavelet transform can be applied in both Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT). The CWT computes the correlation between the signal and the base wavelet at different scales while DWT makes use of filters to analyze the signal at different frequency bands with different resolutions (Quandt et al., 2012).

2.2. Discrete wavelet transform

DWT decomposes any signal into low and high frequency components as approximation and detail, respectively. For most signals, the approximate components include the most important parts surrounding the major signal trends and characteristics. The detailed components illustrate only high frequency parts of the signal (Quandt et al., 2012).

Approximate and details could be obtained by means of high and low pass filtering operations as follows;

$$\begin{cases} a_{j,k} = \sum_m h(m-2k)\, a_{j-1,m} \\ d_{j,k} = \sum_m g(m-2k)\, a_{j-1,m} \end{cases} \qquad (2)$$

Where, $a_{j,k}$ is the approximate coefficient, and $d_{j,k}$ denotes the detailed coefficient. The approximate coefficients at wavelet decomposition level j are obtained by convolving the approximate coefficients at the previous decomposition level $(j-1)$ with the low-pass filter $(h\,(t))$ coefficients. Similarly, the detailed coefficients at wavelet decomposition level j are obtained by convolving the approximate coefficients at the previous decomposition level $(j-1)$ with the high-pass filter $(g\,(t))$ coefficients. The implementation of the DWT is illustrated in Fig. 1 (Gao and Yan, 2011).

2.2.1. DWT thresholding denoising

The removal of noise on actual contents is one of the essential steps in signal processing. A signal or an image is usually affected by a variety of noisy factors during transmission. In current work, the noise is recognized and eliminated in order to reduce its effects on hyperspectral data in the course of extracting important features