Automatic Detection of Absorption Features for Hyperspectral Images

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Abstract: A new method for automatic detection of absorption features is proposed. This method is based on the modulus maximum of the scale-space image calculated by continuous wavelet transform. This method is computationally efficient as compared to traditional methods. The continuum removal algorithm is than implemented on the detected absorption features to reduce some additive factors caused by other absorbing of materials. The results show that the chlorophyll absorption features are detected exactly.

Keywords: Hyperspectral Images, Absorption Features.

1. Introduction

Due to the high spectral resolution of hyperspectral images, it becomes possible to analyze the diagnostic absorption and reflection characteristics of an object over narrow wavelength intervals [1]. The absorption and reflection characteristics are often related to the internal structure of the materials, such as chlorophyll content, nutrient level, water status and leaf structure. In contrast with traditional statistical approaches, the ability to extract such diagnostic spectral features has also renewed interest in deterministic approaches to spectral analysis. One of the most fruitful techniques is the expert-system-based procedures which match the remote sensed spectrum for each pixel to a large library of laboratory spectra of well-characterized materials [2]. This matching is based primarily on the unique absorption features of various material types. Parameters of features in a spectral curve, such as low points and their wavelength locations, width, depth, and symmetry are used for spectral matching. These parameters of features are usually determined based on specific expert knowledge from spectroscopists, geologists and biologists, and are stored in the spectral libraries of the expert system in advance. However, building such a knowledge base is a laborious job and time-consuming.

Several methods have been proposed to automatically locate and characterize the absorption features for the purpose of material identification. Derivative analysis makes use of the fact that the derivative of a function tends to emphasize changes irrespective of the mean level [3]. A common disadvantage of this method is its extreme sensitivity to noise. Piech *et al.* [4] used the symbolic descriptions of spectral features, called fingerprints, as the quantitative indices of the absorption bands to distinguish various materials. Fingerprints are simply obtained from the zero-crossings of a scale space image which is calculated by the second derivative of Gaussian functions. The MMFE (Modulus Maximum Feature Extraction) method proposed by Hsu and Tseng [5], [6] also produces similar fingerprints using wavelet transform. By detecting the positions of modulus maxima of wavelet coefficients calculated using the first derivative of Gaussian, the fingerprints corresponding to the absorption features can be easily delineated. However, the fingerprint obtained by the existing methods does not really cover the whole range of the absorption features.

In this study, an improved algorithm of MMFE, called MMFE2 is proposed to detect the position of absorption features. In order to exactly characterize the whole absorption feature, we use the points with local maximum curvature as the edges of the absorption feature instead of the inflection points. This can be done by using the second derivative of Gaussian function as the wavelet function. Once the absorption features are detected, the continuum removal algorithm is directly applied to these features to remove the effects caused by other absorbing or emitting materials.

2. Wavelet-Based Feature Detection

1) Modulus Maximum Wavelet Transform

The continuous wavelet transform (CWT) of a function $x \in \mathbf{L}^2(\mathbf{R})$ is defined as

$$\mathcal{W}x(u,s) = \int_{-\infty}^{+\infty} x(t) \frac{1}{\sqrt{s}} \psi^* \left(\frac{t-u}{s} \right) dt \qquad (1)$$

where ψ is a specified wavelet function. When the scale s varies from its maximum to zero, the decay of the wavelet coefficients $\mathcal{W}x(u,s)$ characterizes the regularity of x in the neighborhood of u. This characteristic of multi-scale analysis is very similar to the fingerprint method which is based on the scale space filtering. This provides an essential idea in detecting the absorption features from the reflectance spectra by CWT [5], [6].

A wavelet ψ with n vanishing moments can be written as the n^{th} order derivative of a function θ: $\psi = (-1)^n d^n\theta / dt^n$. The resulting wavelet transform is then identical to a multi-scale differential operator [7],

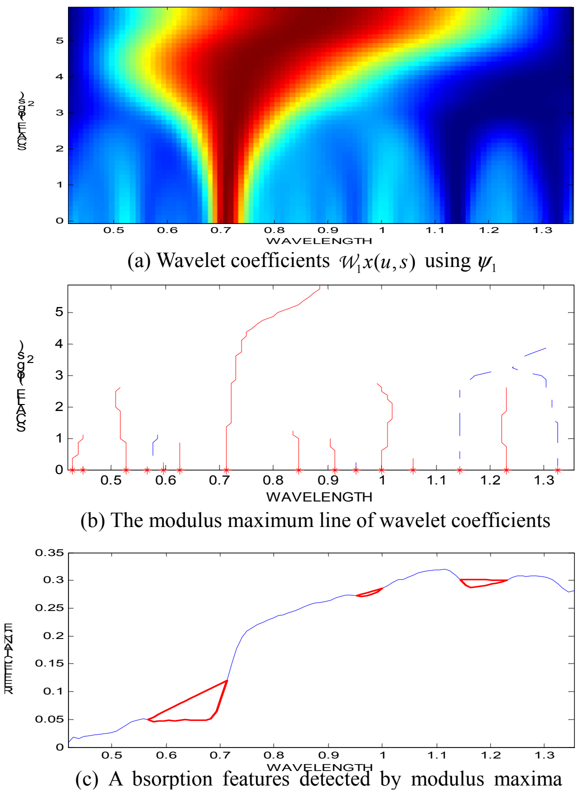
$$\mathcal{W}x(u,s) = s^n \frac{d^n}{du^n}(x * \bar{\theta}_s)(u) \tag{3}$$

where $\bar{\theta}_s(t) = \frac{1}{\sqrt{s}}\theta(-\frac{t}{s})$. Suppose that function θ is a smooth function that the convolution $x * \bar{\theta}_s(u)$ averages $x(t)$ over a domain proportional to s. Thus the wavelet transform of $x(t)$ with respect to a wavelet ψ is equal to the n^{th} derivative of the convolution $x * \bar{\theta}_s(u)$. The smoothing function θ can be viewed as the impulse response of a low-pass filter. An important example often used in signal processing is the Gaussian function.

Let ψ_1 and ψ_2 be two wavelets defined respectively as the first and second derivative of Gaussian function θ. And the wavelet transforms $\mathcal{W}_1x(u,s)$ and $\mathcal{W}_2x(u,s)$ are respective to the first and second derivative of the smooth function $x * \bar{\theta}_s(u)$. For a fixed scale, the modulus maxima of $|\mathcal{W}_1x(u,s)|$ correspond to the inflection points of $x * \bar{\theta}_s(u)$. On the other hand, the modulus maxima of $|\mathcal{W}_2x(u,s)|$ correspond to the points of $x * \bar{\theta}_s(u)$ with the locally maximum curvatures. For all scales, the local maximum points of $|\mathcal{W}_1x(u,s)|$ or $|\mathcal{W}_2x(u,s)|$ can be connected as a set of maximal lines in the scale-space plane (u,s). The usage of Derivative of Gaussians guarantees that all maximum lines will propagate down to the finest scales [7]. By detecting the positions of the local maxima or zero-crossings from the coarse to fine scale, we can obtain the positions of the absorption feature of a hyperspectral curve.

2) Modulus Maximum Feature Extraction

A spectral absorption feature can be defined as a valley contained between two edges over a hyperspectral curve. In MMFE method, the edges are defined as the inflection points with local maximum slope of the hyperspectral curve and can be detected by the modulus maximum wavelet transform when ψ_1 is used as the wavelet function [5], [6]. However, the feature detected by MMFE does not really cover the whole range of the absorption band. In this study, the improved algorithm, called MMFE2, uses ψ_2 as the wavelet function. That is, the edges of absorption features are defined as the points with local maximum curvatures. The consequently detected features can exactly cover the full wavelength range of the absorption bands.

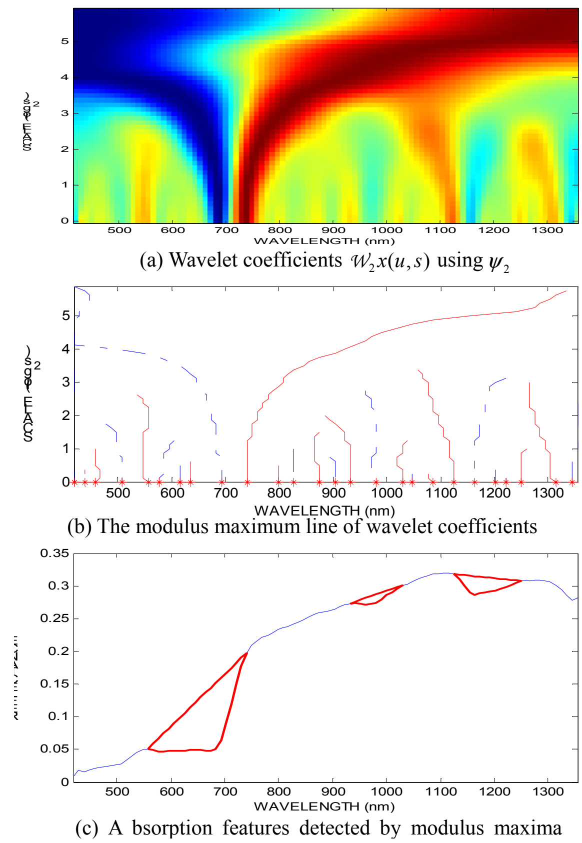


(a) Wavelet coefficients $\mathcal{W}_1x(u,s)$ using ψ_1

(b) The modulus maximum line of wavelet coefficients

(c) A bsorption features detected by modulus maxima

Fig. 1. The absorption features detection by MMFE



(a) Wavelet coefficients $\mathcal{W}_2x(u,s)$ using ψ_2

(b) The modulus maximum line of wavelet coefficients

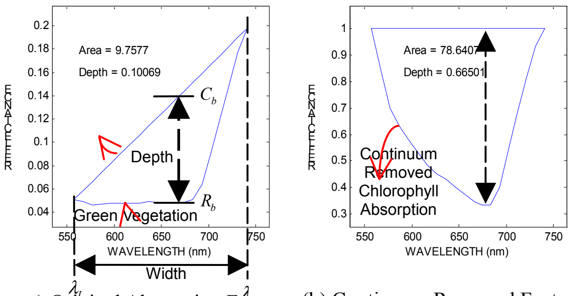
(c) A bsorption features detected by modulus maxima

Fig. 2. The absorption features detection by MMFE2.

Fig. 1 and fig. 2 show the results of absorption feature detected from a reflectance spectrum using MMFE and MMFE2 methods respectively. Note that the absorption features detected by MMFE2 exactly cover the entire wavelength range of the absorption features.

3) Continuum Removal of Absorption Feature

The shape of an individual absorption feature may vary due to some effects, such as level changes and slopes due to other absorbing or emitting materials. These effects can be removed by the continuum removal algorithm [8]. For an individual absorption feature, the continuum can be defined as a straight line whose ends are the edges of the feature. It can be removed by dividing the continuum into the reflectance spectrum data as $L(\lambda) = R(\lambda)/C(\lambda)$, where $R(\lambda)$ is the reflectance spectrum and $C(\lambda)$ is the continuum of the spectrum. Fig. 3 shows an example of continuum removal of a single absorption feature.



a) Original Absorption Feature (b) Continuum Removed Feature

Fig. 3. An example of continuum removal.

3. Experiments

In this experiment, we attempt to detect the chlorophyll absorptions of ten different plants from the AVIRIS data of Jasper Ridge using our proposed method MMFE2. Fig. 4. shows the results of the continuum removed chlorophyll absorptions. The shapes of these continuum removal features reveal some subtle variation of the absorption features. Table 1 listed some parameters of these ten features. Note that the left and right positions of these chlorophyll absorptions are all the same. This demonstrates that the absorptions in this range are caused by the same chemical structure which is actually the chlorophyll of vegetation. Some parameters such as the width, depth and area are also listed in Table 1.

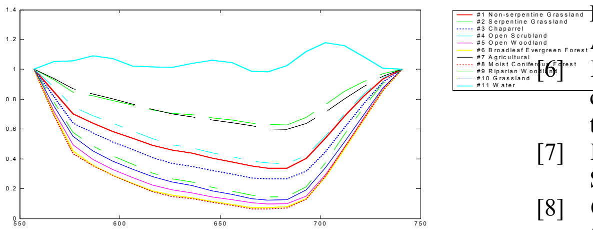


Fig. 4. Continuum removed chlorophyll absorptions

Table 1. Various parameters of the chlorophyll absorption feature for different class.

Class No.	λ_L (nm)	λ_R (nm)	Ori. Width	Ori. Area	Ori. Depth	C.R. Area	C.R. Depth
#1	557.07	740.80	183.73	9.76	0.10	78.64	0.665
#2	557.07	740.80	183.73	4.05	0.04	41.95	0.374
#3	557.07	740.80	183.73	8.00	0.08	91.00	0.736
#4	557.07	740.80	183.73	7.01	0.07	72.93	0.634
#5	557.07	740.80	183.73	14.62	0.14	122.39	0.9286
#6	557.07	740.80	183.73	17.92	0.18	117.70	0.905
#7	557.07	740.80	183.73	6.37	0.07	44.34	0.403
#8	557.07	740.80	183.73	9.52	0.09	123.10	0.938
#9	557.07	740.80	183.73	13.22	0.13	105.59	0.857
#10	557.07	740.80	183.73	22.53	0.23	110.57	0.878

4. Conclusions

In this study, an improved algorithm of MMFE is proposed to automatically detect the absorption features of a reflectance spectrum using wavelet transform. The results showed that the features extracted by MMFE2 exactly cover the full wavelength range of absorption features. Consequently, the left and right positions of absorptions are easily located as the endpoints of the continuum. This helps us to imply the continuum removal algorithm to reduce some additive effects.

Acknowledgement

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