Classification of Forest Stands in British Columbia Using AVIRIS Data: A Preliminary Investigation

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Abstract

Data normalization for removal of atmospheric effects, data reduction (band-moment analysis, feature selection), and integration of Geographic Information System/Remote Sensing data were applied to an Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data set for an investigation of the potential for classification of forest stands within a mountain forest ecosystem. Preliminary classification accuracies of approximately 94%, achieved with the maximum likelihood classifier for the training data selected from homogeneous polygons, indicate that AVIRIS data have some potential for classification.

I. Introduction

Labelling of forest polygons with respect to species composition, tree height and age, crown closure, etc., is an important mandate within the British Columbia Ministry of Forests (BCMOF) for inventorying and inventory updates of the forest resources. The objectives of the inventory program are to develop and maintain a quantitative description of the forest resources in the province. Satellite and airborne imagery are viewed as a potential replacement of aerial photography which is used in the creation of the forest inventory polygons. The identification of homogeneous forest stands is a precursor to implementing a sampling strategy designed to assist in the interpretation of remotely sensed data. The main limitations to successful classification from remotely sensed data remains the non-homogeneity of many of the existing forest polygons.

In this paper, the separability of homogeneous forest polygons is investigated by maximum likelihood classification of band moments generated from the spectral signature of selected homogeneous forest polygons from an Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data set acquired over a forested area in British Columbia, Canada. The homogeneous polygons were identified by integration of the existing Geographic Information System (GIS) forest data base maintained by BCMOF. Moments are summary measures of the spectrum shape and were used to reduce the spectral dimensionality for classical discriminant analysis. Analysis procedures need to be developed to take advantage of the high spectral resolution of hyperspectral data sets such as AVIRIS at the least cost by minimizing the computation time. An additional challenge in the analysis of imaging spectrometer data includes the understanding of the interaction between the spectral signature and the atmosphere for data normalization purposes. The data processing was conducted using the Imaging Spectrometer Data Analyzer (ISDA) software package implemented at the Canada Centre for Remote Sensing (Staenz and Goodenough, 1989).

II. Field Campaign

A. Data Acquisition

AVIRIS data were collected over three forested areas in the Kootenay Valley near Invermere in south-eastern British Columbia, Canada, on August 14, 1990 as part of a multi-aircraft campaign involving the CCRS C- and X-band SAR (Synthetic Aperture Radar) and 8-band pushbroom imager MEIS (Multi-detector Electro-optical Imaging Sensor). These instruments are described in detail by Till et al. (1986), Livingstone et al. (1987), and Porter and Sumark (1987). In addition, Landsat Thematic Mapper (TM) as well as SPOT High Resolution Visible (HRV) multispectral and panchromatic data were also acquired over the test sites together with aerial photography of 1:35,000 and 1:60,000 scales. Available GIS information of the test sites on a 1:20,000 scale include digital terrain models, forest inventory maps and forest attribute information. Ground reference information was collected on a point basis covering a circular area with a radius of 10 m. Such plots were then used to characterize the forest stands in terms of species composition, crown closure, age, nutrient regime, foliar chemistry, etc. Ground-based spectral measurements were carried out for data normalization purposes in an absolute sense over selected reference targets such as water, grass, and gravel.

B. Test Site

The test scene used for the investigation described in this paper is relatively flat with variations in elevation of less than 100 m and is situated between the Columbia and Kootenay Rivers, approximately 900 m above sea level. The climatic condition of the area is dry with a mean annual precipitation of 30 cm and the soil nutrient regime is poor to medium for the different forest stands. The combined influence of soil and climatic factors on vegetation result in the IDF (Interior Douglas Fir) biogeoclimatic zone (Krajina, 1969). Associated main tree species in the area are lodgepole pine (Pinus contorta Dougl.) and yellow pine (Pinus ponderosa Laws.) with some minor inclusion of englemann spruce (Picea englemanni Parry), larch (Larix Mill.), and aspen (Popolus tremuloides Michx.). The 30 to 200 year old forest stands were selectively logged several times over the years resulting in crown closures generally below 60 percent.

III. Data Analysis

A. Preprocessing

Radiometrically corrected (calibrated) AVIRIS data with a total of 224 bands covering a wavelength range from 400 to 2450 nm (Chrien et al., 1990; Green et al., 1990) were analyzed for this investigation. A distinct "herringbone" noise pattern predominated in the first 12 bands. In addition, these bands also indicated a periodic noise pattern in the vertical and horizontal direction (Bailey, 1988). A removal of these fixed noise patterns was not carried out, hence these bands were not included for subsequent analysis. The last couple of bands containing erroneous data due to a low signal-to-noise ratio (SNR) were also eliminated. Overlapping bands between the spectrometers were then eliminated keeping the bands of the spectrometer with the higher SNR.

The data were then normalized using an altitude dependent version of the semi-analytical 5S code (Tanré et al., 1986; Teillet and Santer, 1991a; Teillet et al., 1991b) for a viewing angle dependent removal of the scattering effects and the flat-field approach (Roberts et al., 1986) for a first order correction of the gaseous transmittance. The spectrum from a paved road (main highway), used as a spectrally flat field, was divided into the spectrum of each pixel in the scene after correction for scattering effects. Input parameters for the 5S code run are listed in Table 1. The flat-field normalization technique is already quite effective as demonstrated in Figure 1 for different forest stands before and after normalization. However, the spectra in Figure 2 look more like typical vegetation curves after removing the scattering effects. These spectra have the distinct green peak at 545 nm, the chlorophyll well around 680 nm, and the infrared plateau beyond 750 nm. Most of the atmospheric absorption features were eliminated with the exception of the strong water vapour absorption regions around 1400 nm and 1900 nm. The amplitudes were therefore set to zero in these areas.

B. GIS Information

In order to access the GIS information, the forest cover map was registered to the AVIRIS scene with the nearest neighbour resampling technique resulting in a RMS error of ± 1.50 in the pixel direction and ± 0.95 in the line direction. GIS attribute information characterizing each forest stand (polygon) is then fully available for further processing of the data, i.e., for classification purposes and classification accuracy assessment. Map-to-image registration has the advantage of resampling only the map data (3 thematic channels) and leaving the pixel values in the scene (224 bands) unchanged. In this case, computation time is minimized and the radiometric accuracy is maintained.

C. Data Reduction

Moments were generated from the normalized AVIRIS data set in order to reduce the spectral dimensionality. This procedure was successfully used for the labelling of agricultural targets using imaging spectrometer data acquired with the Programmable Multispectral Imager (PMI) as reported by Staenz and Goodenough (1990). In this case, the band number was used for the band-moment calculations since the PMI bands are evenly spaced. For the AVIRIS data, however, the wavelength was included in the computation due to the different sampling intervals of the spectrometers and the wavelength gap between spectrometers which is on the order of half of the sampling interval. The formulae for the p^{th} moment, M_p, and the central band moment, m_p, for the discrete case are (similar to Rundquist and Di, 1989):

$$M_p = \frac{1}{\Delta\lambda_T} \sum_{\lambda=\lambda_1}^{\lambda_n} [\lambda^P * f(\lambda) * \Delta\lambda] \tag{1}$$

and

$$m_p = \frac{1}{\Delta\lambda_T} \sum_{\lambda=\lambda_1}^{\lambda_n} [(\lambda-\bar{\lambda})^P * f(\lambda) * \Delta\lambda] \quad , \tag{2}$$

where

$$\Delta\lambda_T = \sum_{\lambda=\lambda_1}^{\lambda_n} \Delta\lambda \quad , \tag{3}$$

$$\bar{\lambda} = \frac{M_1}{M_0} \quad , \tag{4}$$

and p = 0,1,2,... is the moment order, $\lambda = \lambda_1, ...\lambda_n$, is the central wavelength in band 1,...n, $f(\lambda)$ is the pixel value for wavelength λ, $\Delta\lambda_T$ is the total wavelength range covered by the sensor, $\bar{\lambda}$ is the wavelength mean, and $\Delta\lambda$ is the average of the adjacent sampling intervals. In addition, the band-concentrated moment was calculated as follows:

$$m_{2c} = \frac{1}{\Delta\lambda_T} \sum_{\lambda=\lambda_1}^{\lambda_n} [(\lambda-|\lambda-\bar{\lambda}|)^2 * f(\lambda) * \Delta\lambda] \quad . \tag{5}$$

The normalized central band and normalized band-concentrated moment can be expressed as

$$\mu_P = \frac{m_P}{M_o} \text{ and } \mu_{2C} = \frac{m_{2c}}{M_o} \quad . \tag{6}$$

Further band-moment ratios were calculated as follows:

$$\gamma_1 = \frac{\mu_3}{\mu_2^{3/2}} \quad \text{and} \quad \gamma_2 = \frac{\mu_4}{\mu_2^2} - 3 \quad , \tag{7}$$

where γ_1 is the coefficient of skewness and γ_2 is the coefficient of excess (kurtosis).

The band-moment approach was applied in the spectral domain on each pixel resulting in the eight moments as follows: (1) ordinary moment (M_o), (2) mean (λ), (3) variance (μ_2), (4) 3rd moment (μ_3), (5) 4th moment (μ_4), (6) skewness (γ_1), (7) kurtosis (γ_2), and (8) band-concentrated moment (μ_{2c}). The computed real values of these moments were then transformed linearly into an 8-bit data set. The advantage of this technique is that it takes the entire spectrum into account and automatically reduces the dimensionality of the data set substantially without detailed knowledge of the spectrum itself.

D. Forest Stand Separability

Percent crown closure was selected as the separability criterion due to the importance of this parameter for growth and yield prediction modelling. Class generation as well as elimination of the non-productive forest and non-forest land was conducted according to the GIS information leaving the productive forest for subsequent analysis. Training samples, varying between 60 and 204 pixels for a specific class, were collected within homogeneous polygons in order to minimize the variation within a class. This selection criterion is important for classification purposes since a polygon can encompass a variety of crown closure classes. In this case, an integrated crown closure estimation of the major species is represented in the polygon label. This parameter derived from aerial photography is related to the timber volume which can cause additional problems for a discrimination of targets using remotely sensed data. The training data set consists of six classes as outlined in Table 2. Each of the classes covers a crown closure range of 10%, except for class six where categories were combined due to the limited number of polygons with a crown closure above 60%. The maximum likelihood classifier was then used to discriminate the training data based on selected band-moment combinations. The best subsets of the eight moments were derived on the basis of a feature selection using the branch and bound algorithm (Goodenough et al., 1978).

The weighted mean classification accuracy (± standard error of mean) varies from 51.67 ± 9.84% for the best single band (band-concentrated moment) to 93.81 ± 0.85% for the entire band set. An acceptable result of 89.56 ± 1.23% was already achieved with the best four-band combination (ordinary moment, variance, kurtosis, band-concentrated moment). Confusion between the crown closure classes could not be resolved entirely as shown in Table 2 for the eight-band combination. These preliminary results should be interpreted with caution because the training data for the crown closure classes were selected irrespective of species, age, height, and site quality. Combining a variety of forest stands into the training data was necessary to cover the full crown closure range for homogeneous polygons. In addition, the reliability of the polygon labels is not known. The results, however, show potential for the use of AVIRIS data in discriminating between homogeneous forest stands with different attributes.

IV Conclusion

Data normalization and data reduction procedures were applied to the AVIRIS data set prior to classification. Atmospheric correction using an altitude dependent version of 5S in order to remove the scattering effects and followed by a flat-field normalization to remove the gaseous absorption effects resulted in typical vegetation spectra for pixels from forested areas. In a next step, the normalized data set was reduced by a factor of 28 using the band-moment analysis approach.

Preliminary maximum likelihood classification of the band moments generated from the spectral signature of homogeneous forest stands resulted in 94% mean classification accuracy for the crown closure training data set. Caution should be used in the interpretation of the results, since the training data set was not controlled for species, age, height, and site quality. However, identification of homogeneous polygons appears possible, implying that potential exists for the use of AVIRIS data in improving or verifying the polygon homogeneity. The identification of homogeneous forest stands, combined with ground reference information, is a prerequisite for forest classification purposes using remotely sensed data.

Acknowledgement

The authors wish to thank the Inventory Branch of the British Columbia Ministry of Forests for their support of the entire project, and D.G. Goodenough and J.-F. Meunier for their assistance in data processing. Our thanks go to A. Kalil for word processing the manuscript.

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TABLE 1: 5S input parameters.

Atmospheric model	No gaseous absorption
Aerosol type	Continental model
Date of overflight	August 14, 1990
Solar zenith angle	35.69 degrees
Solar azimuth angle	182.73 degrees
Sensor zenith angle	Variable
Sensor azimuth angle	32.68 degrees
Ground elevation	0.900 km
Sensor altitude above sea level	19.844 km
Horizontal visibility	50 km

TABLE 2: Confusion matrix between six crown closure classes generated with the maximum likelihood classification procedure for the eight-band training data set. The crown closure classes are: (1) 6-15%, (2) 16-25%, (3) 26-35%, (4) 36-45%, (5) 46-55%, and (6) >56%.

CLASS	1	2	3	4	5	6
1	93.0	3.0	0.8	0.0	0.0	0.0
2	6.6	93.9	2.7	0.0	0.0	0.0
3	0.4	3.1	96.5	0.0	0.0	0.0
4	0.0	0.0	0.0	92.3	2.0	7.6
5	0.0	0.0	0.0	2.3	93.8	3.0
6	0.0	0.0	0.0	5.4	4.2	89.4
Unclassified	0.0	0.0	0.0	0.0	0.0	0.0

Figure 1a:

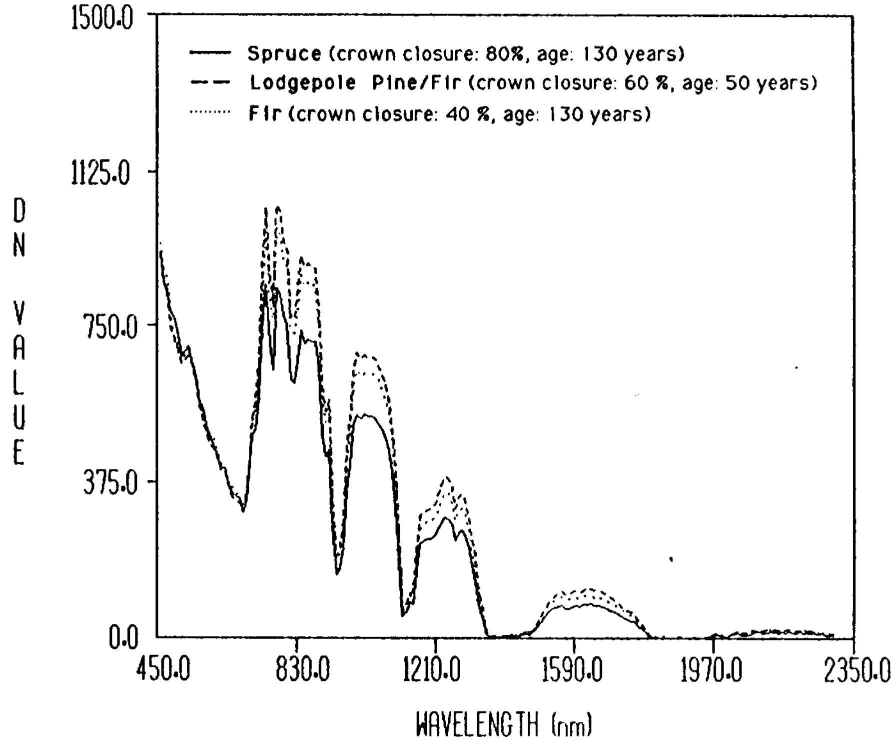

Figure 1b:

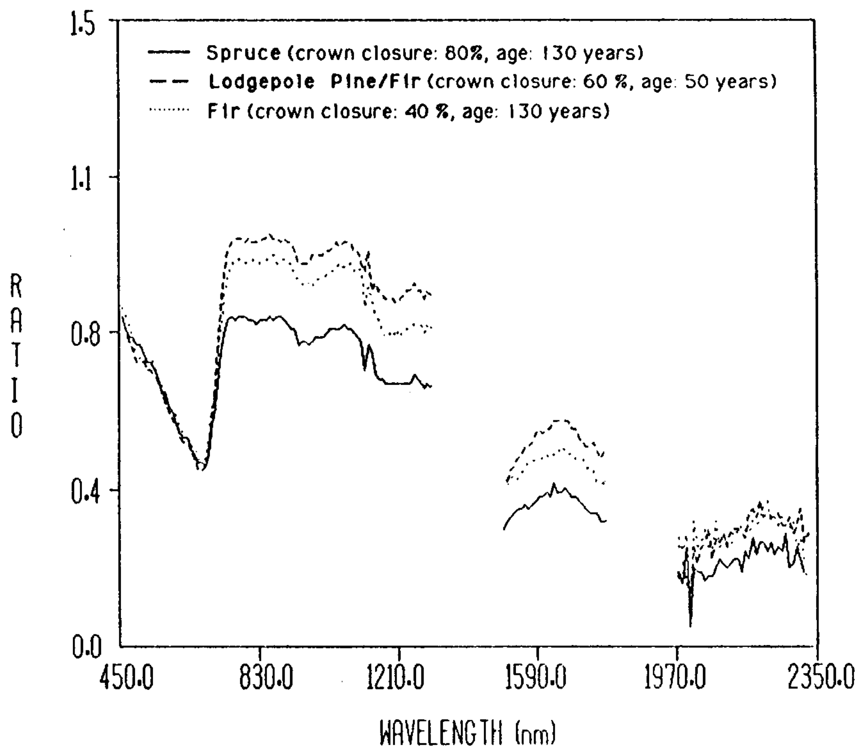

FIGURE 1: AVIRIS spectra of different forest targets (a) before and (b) after relative normalization using the flat-field approach.

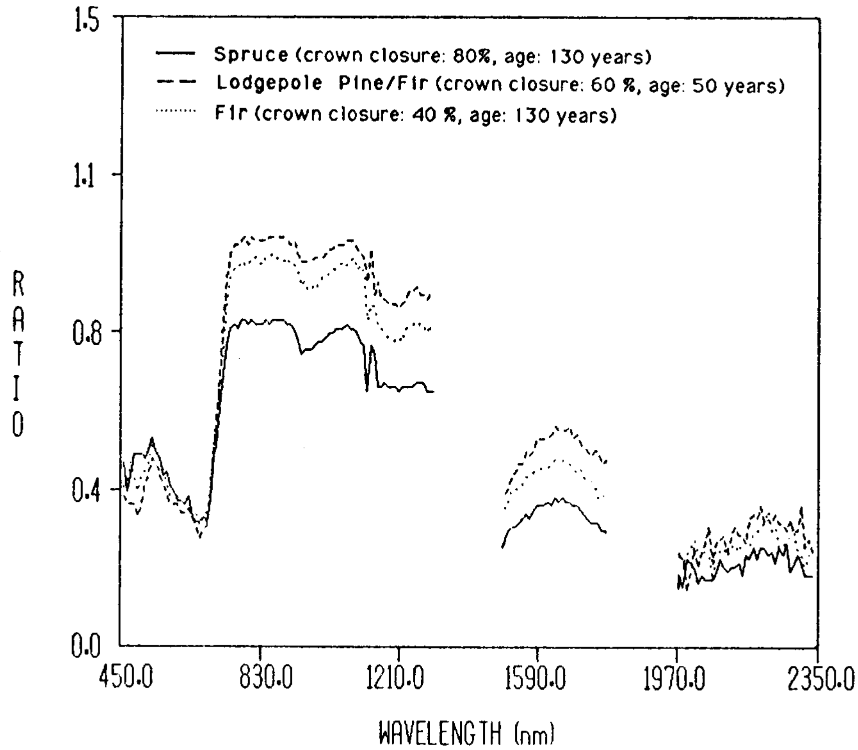

FIGURE 2: Data normalization applied to the spectra of Figure 1a using the 5S code followed by the flat-field approach.